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# FIRE LOSSES
# LOCOMOTIVE SPARKS

BY

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Dedicated to

Dr. W. F. M. Goss

IN APPRECIATION OF HIS PIONEER AND CONSTRUCTIVE RESEARCHES IN THE REALM OF RAILWAY MECHANICAL ENGINEERING AND FOR HAVING FIRST COMPREHENSIVELY ANALYZED AND DEVELOPED MEANS FOR SECURING FUNDAMENTAL DATA PERTAINING TO THE LOCOMOTIVE SPARK PROBLEM AND FOR THE INSPIRATION THAT I HAVE RECEIVED BY VIRTUE OF HIS DISTINGUISHED ACCOMPLISHMENTS, HIS SYMPATHETIC INTEREST, ENCOURAGEMENT AND CORDIAL FRIENDSHIP.

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# PREFACE

The author for a number of years was actively concerned with all problems that confronted the mechanical departments of the railways of the United States. As a designer of locomotives and the appurtenances thereto, a study of the means of securing sufficient draft for high rates of combustion of coal became imperative which high rates of combustion contribute materially to spark formation. A consideration of the operation and performance of locomotives, brought to the fore the problem of preventing fire-carrying sparks. These facts coupled with the knowledge that the railways of the United States were confronted annually by many law suits for damages from fires alleged to have been started by locomotive sparks, led the author to study all available literature bearing upon any phase of the locomotive spark problem. As it was found that there was very little literature bearing upon the subject certain experiments were undertaken whereby the gaps in available literature on the subject might be closed.

The purpose of this treatise is to set forth the facts disclosed as a result of some five years of intense investigation of locomotive sparks and their relation to fires occurring along the right of way of American railways.

In conducting the investigations, every known question that had arisen in connection with law suits for damages from fires alleged to have been started by locomotive sparks was studied. This treatise, therefore, covers all points that have come up insofar as the author has any knowledge.

The treatise supplies information pertaining to: fundamentals of locomotive construction, maintenance and operation from the stand point of the locomotive spark; statement of the extent and seriousness of the fire hazard from locomotive sparks; discussion of the formation of the spark and means adopted to prevent its escape from the locomotive stack; how various types and conditions of coal affect the problem; the quantity and size of sparks ejected by different types of locomotives while being operated under various circumstances of tonnage, speed, weather conditions and the like; the weight and character of sparks caught at known distances from the center of the track; the temperature at which sparks of different size strike the ground at known distances from the center of the track; temperature at which a wide range in size and character will ignite dry combustibles; effect of wind velocity upon the distance to which sparks are carried, height to which sparks are ejected; effect of different types of netting upon the quantity, size and fire carrying properties of locomotive sparks.

No claim is made for originality in the methods used as they were developed by Dr. W. F. M. Goss some years previously. However, the investigation did cover many phases of the problem that had not been so treated hitherto. It is believed that this work is of value in that it focuses attention on certain fundamental factors and discloses data not heretofore available.

The author wishes to take advantage of this opportunity to express his gratitude and indebtedness to all who assisted in the preparation of data for this treatise. The author is especially indebted to: the officials of Purdue University; the I. C. & L. (Monon); the C. C. C. & St. Louis (Big 4); the St. Louis and the Southwestern (Cotton Belt) railway companies, and to Prof. G. A. Young of Purdue University; Mr. H. C. May of the Monon Railway Co.; Mr. E. S. Pearce of C. C. C. & St. Louis Railway Co.; Mr. S. G. Seabrook of St. L. & S. W. Railway Co.; Mr. Henry Tierney of M. K. & T. Railway Co. to Mr. J. E. Hannum and Mr. O. S. Beyer of New York, and to many who, while students in Railway Mechanical Engineering at Purdue University, rendered valuable assistance.

L. W. W.

Washington, D. C.,
*May,* 1923.

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# FIRE LOSSES—
# LOCOMOTIVE SPARKS

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## PART I

# FIRE LOSSES—LOCOMOTIVE SPARKS

## PART I

## CHAPTER I

### INTRODUCTION

**1. Railroad Fires.**—It is not difficult to visualize the conditions peculiar to the railway industry of the country which make railway fires and their prevention a problem of special character having certain national aspects. The elements of personnel organization, nature of territories traversed, climatic conditions, commodities to be transported, together with the mechanical characteristics of the railroad plant, especially the locomotives, all tend to influence the fire situation as it is related to steam transportation.

The special nature and peculiar difficulties of railway fire prevention have resulted in individual and collective action by railway and public organizations and officials. Special operating and maintenance rules and regulations have been established, many detail devices and methods have been developed and placed into service, laws have been passed and agencies established to enforce their observance, all for the purpose of reducing railroad fire hazard. These various activities have reacted upon one another so that considerable progress has been made in this direction in recent years. Nevertheless, a comparison of the extent of the railroad fire losses still existent with the amount of the losses in other countries and on railroads which have concentrated on fire prevention clearly shows that much remains to be done in order to reduce these losses to the reasonable minimum.

The National Board of Fire Underwriters, through its acturial bureau has made a very careful compilation of fire loss statistics for the five years of 1915 to 1919. The aggregate property loss for these years has been found to be no less than $1,416,375,845. The forest fire loss in the United States for the years 1916 to 1920, according to authentic government figures applicable to 45 states was $85,715,747. Using these two figures as a basis, the indications are that the total average annual fire losses of this country exceed $300,000,000. In fact the compilations of the National Fire Protection Association for the year 1920 indicate that the losses more nearly equalled $500,000,000. The year 1920, however, was somewhat abnormal in this respect.

The belief is rather commonly held that the railroads are responsible for a large portion of the forest fires of the country and also cause an appreciable share of other fires. The actual financial losses to railroads resulting from so-called railroad fires has been averaging annually about $12,000,000. Add to this sum the costs for office, legal, insurance, inspection, extra maintenance, patrol and special fire protection services, and the conclusion is warranted that the railroads of the United States must meet an outlay of at least $15,000,000 to $20,000,000 annually because of the fire hazard inherent in their operation.

This visible expense of $12,000,000 is caused directly by actual fires to railroad property such as rolling stock, buildings and supplies, and to private property such as freight in transit, private rolling stock, and buildings and products belonging to private owners along the rights of way. It does not include the losses from fire to national and state forests, and other public properties, caused or alleged to have been caused by railroads. The total number of forest fires, according to government figures for the years 1916 to 1920 inclusive, was 159,824. Of this total 23,847 or 14.9% are charged as having been started by railroads. This is the largest single class of the eight listed, except for the fires of "unknown" origin, composing 24.2% of the total. As already indicated the total damage caused by all the fires to public forests in the United States for the years 1916 to 1920 inclusive, amounted to over $85,000,000. The total timber area of both public and private forests burned over every year, based on recent statements of the Chief Forester of the United States Forest Service, ranges annually from 8,000,000 to 10,000,000 acres.

Recent reports from some states, however, indicate that railroads are responsible for more than 14.9% of the forest fires. Thus the State Forester of Connecticut finds that for the decade 1910 to 1919 inclusive, of the 8,858 forest fires reported, 33% were charged to railroad locomotives. In the New York State Adirondack Forest Preserve disastrous fires occurred in 1893, 1899, 1903 and 1908. The Public Service Commission of the State of New York, Second District, held a public hearing at which railway representatives and other interested parties were present. These hearings indicated that the railroads traversing forested regions were largely responsible for the fires occurring in these regions; and locomotive sparks were considered to be the chief cause.

The seriousness of the railway fire situation, together with the problematical and controversial aspect of many of the causes underlying such fires, not only brings to the fore the important tasks and responsibilities of railway administration and operation but also emphasizes the value of scientific data applying to railway fire causes and prevention developed in recent years. The responsibilities of railroad corporations, federal and state agencies, scientific societies and voluntary organizations interested in fire prevention may be placed into three classes. First, the reduction of the railway hazard to a minimum. Second, the protection of railroad companies against undue and unjust claims, and vice versa, the protection of private and public interest against fire damage and loss for which railroads are responsible. Third, the development and publication of sound scientific information bearing on railway fires, their causes, and the best ways to prevent them.

A survey of the existing literature which deals with the entire phenomena of railway fires, as well as a review of many legal proceedings growing out of claims for fire damages against railway corporations, reveal the fact that the need has existed quite continuously for basic data applying to the subject as a whole. Dr. W. F. M. Goss, while still at Purdue University, made extensive and original engineering investigations especially concerning the likelihood of fire from locomotive sparks. He published his findings in 1902 in a treatise entitled "Locomotive Sparks."[1] Since then many additional tests have been made by others, and the locomotive has undergone many changes in design and construction, all of which has modified the locomotive spark problem considerably.

Preceding paragraphs have clearly shown that railroads are charged with the responsibility for a large proportion of the annual fire losses of the country. The actual facts concerning the detailed circumstances surrounding the origin of such fires are not easy of determination, so that claims allocating the source of such fires to railroad operation are very frequently based on opinion and conjecture, not on facts. Jointly with all this, the vigilance of the state governments as exercised by their agencies has materially increased and is still continuing to grow. Thus the entire subject of railway fires, their causes and prevention, is becoming of greater and greater importance. Hence any basic data, scientific facts, and other sound information, especially applying to locomotive sparks and their relation to the problem, are bound to be of great value both as a guide for possible remedies and as a help in the settlement of complicated controversies.

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[1] "Locomotive Sparks," W. F. M. Goss, John Wiley & Sons, N. Y.

## CHAPTER II

# THE REGULATION OF RAILROAD FIRE HAZARD

### I. STATE CONTROL

The extent and seriousness of fires originating along steam railways has raised a distinct question of responsibility and liability of railway companies for such fires. In all states the common law requirements basically make it necessary for railroads to exercise proper precautions to reduce fire hazards. However, many states, in more recent railway and conservation legislation, have included special provisions having the same object in view. Still other states which have created public utility and conservation commissions have empowered these commissions to exercise definite jurisdiction over railroads for the purpose of controlling the likelihood of fire from such sources.

**1. Common Law Requirements.**—Obviously, under the common law, railroads are obligated to exercise due care and precaution to prevent fires. Should railroads under the common law be sued for damages caused by fires alleged to have been started because of their operation, they must show not only that proper care was exercised in operating their equipment but that such equipment had been adequately provided with the best and most approved appliances employed for fire prevention. For instance, in the event it is proven beyond question that a certain locomotive was involved in a damaging fire, then the railroad company operating this locomotive must show that it was equipped with the most approved devices for preventing the escape of dangerous fire carrying sparks from the stack and for preventing the escape of burning particles of coal from the fire box ash pan. The railroad must further demonstrate that such approved appliances have been diligently and carefully inspected as well as adequately maintained. Thus in Nebraska, where there is no statutory provision covering locomotive spark arresters, a recent direct expression of the court on the subject defines by implication the liability of the railroads in this respect:

> ". . . If at the time the fire escaped from the engine, the locomotive was equipped with the best or most approved appliances that were known, or that should have been known, by the defendant, and in general practical use under such circumstances as surrounded the particular locomotive, and these appliances were in good repair, the defendant was not guilty of negligence in the matter of that equipment. Spaulding v. Chicago & N. W. R. R. Co., 30 Wis. 110; Hagan v. Chicago, D. & C. G. T. J. R. R. Co., 86 Mich. 615; Southern R. R. Co. v. Thompson, 129 Ga. 367." (Bradley v. Chicago, Burlington & Quincy Railroad Co., 90 Neb. 28.)

**2. Additional Liability in Some States.**—Some states, notably Ohio, Massachusetts, Indiana, and Missouri, reverse the ordinary common law requirements and specifically prescribe that railroads shall be liable for damage caused by fires for which they are responsible irrespective of the exercise of due care and precaution on their part to prevent such fires. As an example of this attitude, Section 8970 of the laws of Ohio applying to railroads may be cited:

> "*Sec.* 8970. Every company, or receiver of such company, operating a railroad or a part of one shall be liable for loss or damage by fires originating upon the land belonging to it caused by operating such road. Such company, or receiver of such company, further shall be liable for all loss or damage by fires originating on lands adjacent to its land, caused in whole or in part by sparks from an engine passing over such railroad, and the exercise by such company, or receiver of such company, of due care in equipping and operating such engine shall not exempt such company, or receiver of such company, from such liability, which may be recovered before any court of competent jurisdiction within the county in which the lands on which such loss or damage

occurs are situated. The existence of fires upon the railroad company's lands is prima facie evidence that they are caused by operating such railroad. Provided that nothing herein shall invalidate or prohibit contracts of such company or receiver now existing or hereafter made, by which such company or receiver is indemnified against such loss or damage by fire, or liability therefor released." (Page and Adams Annotated Ohio General Code.)

**3. Limited Requirements of General Application.**—Many states, among them Virginia, Connecticut, Minnesota, and Ohio have also laid down certain limited requirements of general application with reference to railroad fire prevention. Section 8966 of the Ohio laws makes the following provision:

"*Sec.* 8966. Except in the months of December, January and February, any company or person operating a railroad or part of one, shall place on every locomotive engine used therefor, or in construction or repair on the road, such device or contrivance as most effectually will guard against the escape of fire or sparks that otherwise would be thrown out by such engines, and keep the device in good repair." (Page and Adams Annotated Ohio General Code.)

Another good example is furnished by Section 4410 of the Minnesota laws:

"*Sec.* 4410. *Prevention of Fire.*—Every company operating a railroad shall use upon each locomotive engine a good and efficient spark arrester, which the master mechanic shall be caused to be examined each time before leaving roundhouse, and the master mechanic and the employee making such examination shall be held responsible for the good condition of the same, but without relieving the company from its responsibility hereunder.

"Every such company shall keep its right of way clear of combustible materials, except ties and other materials necessary for the maintenance and operation of the road, from April 15 to December 1.

"No company shall permit any of its employees to leave a deposit of fire, live coals or ashes in the immediate vicinity of wood land or lands liable to be overrun by fire, and every engineer, conductor or trainman discovering fire adjacent to the track shall report the same promptly at the first telegraph or telephone station reached by him.

"In dry seasons every such company shall give its employees particular instructions for the prevention and extinguishment of fires, and shall cause warning placards furnished by the forestry commissioner to be conspicuously posted at every station in the vicinity of forest and grass lands, and, when a fire occurs near the line of its road, shall concentrate such help and adopt such measures as shall be available for its extinguishment.

"In dry seasons every such company shall employ at least one patrolman for each mile of its road through lands liable to be overrun by fire to discover and extinguish fires occurring near the line of the road, by which is meant a distance within which a fire could easily be set by sparks from a passing locomotive.

"Any company violating any provision of this section shall be deemed guilty of a misdemeanor, and, on conviction thereof, shall be fined not less than fifty dollars and not exceeding one hundred dollars and costs of prosecution for each offense, and any railroad employee violating ths same shall be guilty of a misdemeanor, and shall be punished by a fine of not less than fifty dollars nor more than one hundred dollars and costs of prosecution, or by imprisonment in the county jail not exceeding ninety days."

**4. Special Requirements of Limited Application.**—Finally, it is of interest to note the attitude of some states which have established both public utility and conservation or forestry commissions. The basic acts creating such commissions grant certain regulatory powers to the commissions as applying to railway properties and equipment. These powers are invoked to establish both limited rules and regulations of general application and special and stringent requirements of limited application. Under this arrangement the State of New York, for instance, through both its Public Service Commission and its Conservation Commission, has issued special rules and regulations from time to time requiring railroads operating through the Adirondack and other forest preserves to provide extraordinary measures of precaution, such as burning oil in locomotives instead of coal and establishing special fire patrols.

An act of June 3, 1915 (P. L. 797) authorizes the Chief Fire Warden of the State of Pennsylvania to declare certain property forest fire hazards. This has been interpreted to permit the inclusion of railroad locomotives in such property, should occasion warrant. In addition this same law authorizes the Chief Fire Warden to submit rules and regulations for steam railroads to the Public Service Commission, and if they are approved by that Commission they become effective and must be put into operation by railroad companies.

Along the line of both general and special requirements laid down for railway fire prevention, the developments in the Dominion of Canada are of particular interest because of their nation-wide scope. The Board of Railway Commissioners for Canada, located at Ottawa, includes among its operating departments a Fire Inspection Department. The Board has issued a very comprehensive and thorough general order, No. 107, which lays down in great detail the requirements which each railroad coming under its jurisdiction shall observe. The Fire Inspection Department is delegated to supervise the carrying out of these requirements and in addition is authorized each year to issue special instructions with reference to the establishment and maintenance of fire guards on both sides of the right of way of railroads.

**5. Locomotive Specifically Considered.**—Since the locomotive is apparently considered the main offender, most of the special action taken by various states and their commissions has been concentrated upon it. A general survey of this development indicates a tendency towards increased stringency of the provisions promulgated from time to time. This is perhaps only natural when the growing significance of the conservation movement is considered. Thus a distinct premium is being placed upon the further development and application of satisfactory ways and means for reducing the fire hazard of the steam locomotive.

## II. VOLUNTARY REGULATION AND CONTROL

**6. The American Railway Association.**—The American Railway Association has investigated the subject of railway fire prevention, and in November, 1919, put into effect an approved set of rules for the Prevention of the Spread of Forest and Field Fires. These rules are specifically set down as "minimum requirements" supplementary to state laws and regulations. In addition they urge the coöperation with other agencies, state, national and private, which seek to improve the railway fire situation. Specifically and in detail they are as follows:

### RULES FOR THE PREVENTION OF THE SPREAD OF FOREST AND FIELD FIRES[1]

**Precautionary Measures.**

1. Railroads shall not permit fires, burning waste, live coals, ashes, wood or other substances in a burning state to be deposited on tracks or right of way, unless such fires are completely extinguished immediately thereafter; except where such fires are deposited in pits provided for that purpose, or deposited on parts of track specially designated as being safe for such purpose.

2. Railroads shall take the necessary measures to maintain tracks and right of way in safe condition to prevent the spread of forest, prairie and field fires.

Preventive measures shall be taken in all cases where coal- or wood-burning locomotives are operated through districts where there is possibility of fire running. In general, such measures shall be as follows:

**Disposal of Inflammable Material.**

(*a*) All inflammable material, such as standing dead trees, logs, dead or decayed wood, brush, dry leaves and dry grass, within the limits of the right of way, shall be burned off early in the spring months, and as often thereafter as may be deemed necessary.

**Supervision of Burning Operations.**

3. No railroad, through its agents, employees, or contractors, shall burn, or cause to be burned, any cross- or switch-ties, mowings, debris, or other litter on or near the right of way except under proper supervision, to prevent such fires from spreading beyond control. During the period of greatest fire danger, no such burning shall be done by the railroad forces.

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[1] Adopted by American Railway Association, November 19, 1919.

**Reporting Fires.**

4. Railroads shall instruct and require stationmen and other employees, agents, or contractors, to report fires and extinguish same when on or adjacent to the right of way, as follows:

(*a*) Enginemen, conductors, or trainmen, who discover or receive notice of a fire burning upon or adjacent to the right of way, or of a fire which threatens land or property located adjacent to the right of way, shall report its existence and exact location by milepost to the agent or person in charge at the nearest point where communication by telegraph or telephone is available, and also notify the first section employees passed. Notice of such fire shall also be given immediately by enginemen by a system of warning whistles.

(*b*) The agent or other employee of the railroad shall at once notify the nearest section employees, and, if possible, the nearest Federal or State Forest Fire official, of the existence and exact location by milepost of such fire.

(*c*) When a fire is reported or discovered burning adjacent to the right of way of a railroad, regardless of its origin, such sectionmen or other employees of the railroad as are available shall at once proceed to the location of the fire and extinguish it, provided such sectionmen or other employees at the time are not engaged in work essential to the safe operation of trains.

(*d*) Railroads operating through forest districts shall provide suitable blank forms for reporting fires occurring on or adjacent to the railroad right of way, regardless of their origin. Section foremen shall be instructed and required to make detailed written report on the prescribed form of any fire, however trivial, and to forward such reports promptly to their superior. The intent of this rule is to determine and, if possible, to eliminate the causes of fire.

**Special Instructions.**

5. Railroads shall issue special instructions to employees concerning the foregoing rules or regulations. Such rules or regulations shall be posted on bulletin boards or round houses, section houses, stations, and in conspicuous places on other parts of the right of way of the railroad.

**Coöperation with Other Agencies.**

6. In view of the aid that may be rendered by the various State Forest Fire Protective organizations, the officers of the Forest Service of the United States Department of Agriculture, and Timber Owners' Protective organizations, the closest possible coöperation by railroads with such agencies, wherever they exist, is desired and encouraged. The details of such coöperation between the railroad forces and the protective organizations is to be arrived at by mutual agreement between the parties concerned.

**Minimum Requirements.**

7. The foregoing rules or regulations constitute minimum requirements. It is not intended that they shall supersede state laws or regulations where additional measures are in effect, but they are supplementary thereto.

**7. The Railway Fire-protection Association.**—This association, composed mainly of railway officers specifically interested in railway fire prevention, was organized in 1913 for the purpose of investigating, considering and discussing the best ways and means devised to prevent railway fires. Through committees and individuals, special reports and papers are prepared which go into the various phases of this problem. At the same time, producers of devices designed to reduce railway fire hazards utilize the meetings of this association for general educational purposes.

Among other subjects, this association, through a committee, has investigated and reported on Locomotive Sparks and Ash Pan Hazards. While it summarized the situation to a certain extent as of the year 1916, it refrained from making definite recommendations which might have proved of value and guidance.

**8. Locomotive Inspection and Maintenance.**—Aside from the special provisions laid down by state laws and regulations applying to particular devices and means for preventing fires from locomotive sources, the greatest emphasis by implication or otherwise is necessarily placed upon proper inspection and maintenance of locomotive ash pans and spark arresters. These are of the very greatest importance as means for eliminating the danger of fire from locomotives. The common law distinctly places the burden of proper inspection and maintenance upon the railroads. Furthermore such special state laws and regulations as exist clearly demand that this obligation be met, and often provide special means for enforcing its observance.

The importance of this matter was thoroughly appreciated by the United States Railroad Administration during federal control of railroads. The whole subject was investigated, and after thorough consideration and discussion by the Committee on Standards of the Mechanical Department, a set of rules was prepared governing the care and inspection of ash pans and spark arresters of locomotives. The practices and experiences of most of the main roads as well as of the responsible authorities of interested states were taken into consideration in the formulation of these rules. Since they undoubtedly represent the most approved minimum requirements, they are of considerable value. As issued by the Federal railroad administration they read as follows:

### INSPECTION OF ASH PANS AND SPARK ARRESTERS[1]

**"To Railroads:**

"The following rules will govern in the care and inspection of ash pans and spark-arresting appliances in locomotives used on railroads under Federal control:

"1. A careful and thorough inspection of every part of the spark-arresting appliances in front end of locomotives must be made every time the front end door is opened for whatever purpose; but at intervals of not more than seven days, and at the same time, the ash pans, hoppers, slides, or other apparatus for dumping cinders and dampers must also be inspected. Observe if the slide or hopper operates properly and closes tight. When conditions such as extreme drought or the state of adjoining property or crops require it, this inspection must be made at least once every twenty-four hours.

"2. A record of condition on arrival must be made under the proper heading on an approved form, immediately following each inspection, with the date made, together with a complete statement of any repairs or renewals required. The above record to be made and signed by the person who made the inspection.

"3. Nettings and spark arresters must be put in perfectly tight and serviceable condition before the locomotive is put into service. Renew netting and plates in front end when worn thin or defective, instead of patching them. Ash pans and hoppers must be tight, and dampers, slides, or apparatus for dumping cinders must be in good working order, closing tight.

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[1] United States Railroad Administration, Mechanical Department Circular No. 5, Oct. 7, 1918.

"4. Record of repairs and renewals made must be entered under the proper heading on an approved form when repairs have been made, with the date; the entry to be made and signed by the person doing the work.

"5. These are the minimum requirements, and local conditions or regulations requiring additional precautions are not affected thereby."

**9. Conclusion.**—From the foregoing it is quite evident that locomotives play perhaps the most prominent part in the problems of railway fire prevention. This conclusion is based upon such statistical and other evidence as is available. However, some doubt cannot be avoided with respect to the reliability of the information concerning at least some of the fires alleged to have been started by locomotives, especially by sparks issuing from locomotive stacks. Rightly or wrongly, the opinion prevails that the locomotive is the worst offender, presumably because of the fact that a certain quantity of sparks are ejected from the stack. The locomotive as a fire hazard, from this point of view, needs to be further investigated. Much of the data heretofore published on the basis of which locomotives are largely being judged, was gathered during an era when the size of the locomotive and the operating demands upon it were not anywhere as extensive or as severe as they are now, nor when improvements in the design and construction of spark-arresting devices were as highly developed as they are today. Indeed, many of the developments in legal control and public action affecting the locomotive as a fire hazard have been predicated upon unscientific data and insufficient facts, not upon an understanding of all the fundamental principles involved. Nor has the design, construction, operation and maintenance of such an important fire prevention device as the spark arrester always been based upon a full knowledge of the principles involved.

Nevertheless, the spark-arresting features of the steam locomotive, from the simple mechanical viewpoint, are in much better shape than is the knowledge possessed concerning the peculiarities of locomotive sparks proper, i.e. their quantity, fire-carrying characteristics, ignition powers, and distribution after leaving the locomotive stack. Fires caused by locomotive sparks and the controversies which almost inevitably result therefrom will never be reduced to a minimum until this particular phase of the problem is thoroughly understood. Perhaps the major contribution to the solution of the problem in the pages to follow will be the additional light shed upon the behavior of locomotive sparks after they leave the stack.

## CHAPTER III

## THE MODERN STEAM LOCOMOTIVE

The modern steam locomotive is a very ingenious device, especially when the limits are considered within which it must be designed, constructed and operated. It is a particular kind of power plant intended for a very definite purpose and quite in a class by itself. One of these limits within which it must function and which presents its own set of complications is that imposed by the necessity of preventing the ejection of fire-carrying sparks and cinders from the stack. Hence a consideration of its construction and operation will be helpful in comprehending the true nature and peculiar difficulties of the spark prevention problem. Above all, the conflict between the necessity for providing adequate fire box draft, while at the same time preventing dangerous spark formation will only then be fully appreciated when the main features of the locomotive as a power plant intended for heavy fast pulling purposes are understood.

**1. Description of the Locomotive.**—A modern freight locomotive known as the Mikado, or 2-8-2, type is illustrated in Figure 1. The view is a longitudinal cross section and shows quite well how the locomotive is constructed. Its essential parts in general are classified respectively as the boiler and as the machinery. The tender which carries the fuel and water is also a part of the locomotive, but it is auxiliary rather than essential.

**2. The Machinery.**—The machinery of the locomotive consists primarily of two simple or single expansion steam engines which are indicated in Figure 1. These two engines jointly turn over or drive the wheels or locomotive drivers through what are known as the main and side rods. The engines, rods, and wheels are all coupled together into an integral unit so

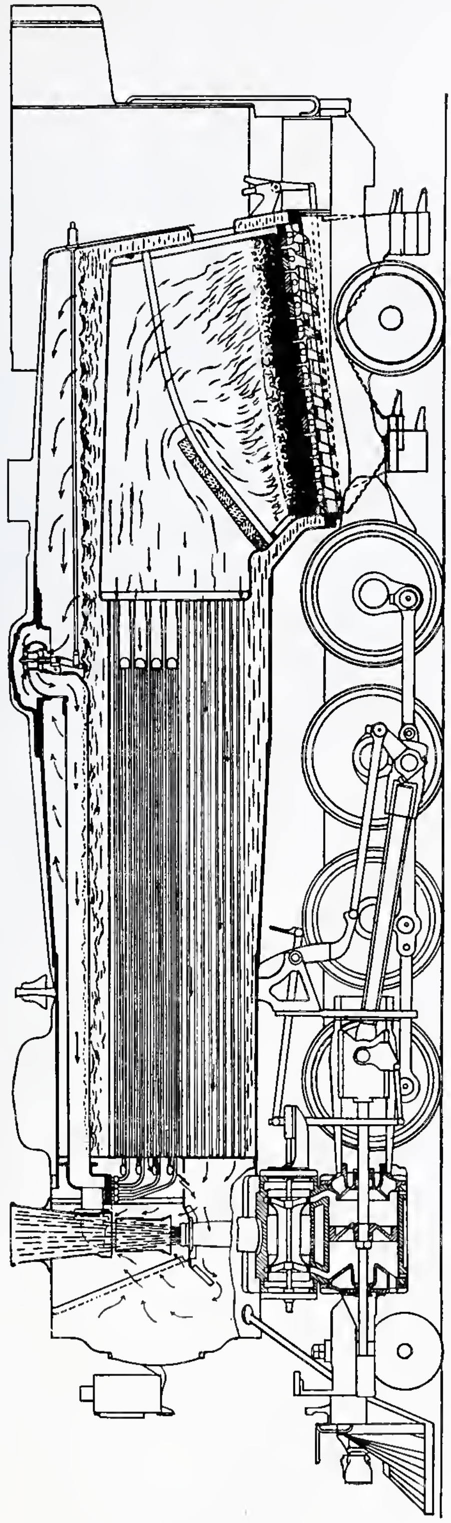

FIG. 1.—Longitudinal cross-section of a Mikado or 2-8-2 type freight locomotive.

that one part cannot move without affecting the other parts. As the locomotive wheels turn over, the locomotive moves forward and exerts a pulling force at the tender coupler; that is, where the locomotive is attached to its train of cars.

**3. The Boiler.**—The agent which enables the two engines to exert this pressure or power to the locomotive drivers is steam under high pressure which is supplied by the locomotive boiler. It is formed in the boiler by the very rapid boiling or evaporation of water.

The boiler, as will be noted from the illustration, consists of a round shell joined to a sort of inverted U-shaped double box ordinarily known as the back end or fire box end of the boiler. This back end is really a water space which surrounds the furnace or fire box of the locomotive and as such is integral with the inner or water space of the round part or shell of the boiler. It will be further noted that the cylindrical portion of the boiler is equipped with tubes securely held in place by so-called flue sheets at the fire box and front ends. These boiler tubes and flues pass directly through the water space of the round part of the boiler and in this position naturally are entirely surrounded on their outside by water. It is through these tubes that the products of combustion, that is, the hot gases, flames, smoke and sparks created in the fire box pass to the front end or smoke box, from which they are ejected through the stack into the atmosphere. It is these products of combustion which in passing over the fire box and tube surfaces give up their heat to the water, converting it into steam.

**4. The Fire Box.**—The fire box of the boiler is provided with a floor of castings ordinarily known as grate bars. Hence, the term fire box grate surface for this floor. These bars are made of cast iron and are provided with a series of regular holes or air spaces which enable the air required for combustion to get to the fuel bed. Approximately one-quarter of the total grate surface is composed of these air openings. This surface serves as the foundation for the fire which supplies the heat to the boiler water.

Furthermore, an opening is provided, properly designated in Figure 2, through the back wall or leg of the fire box end of the boiler, called the fire door. The fuel for the fire is usually fed by means of a scoop in the hand of the fireman through this

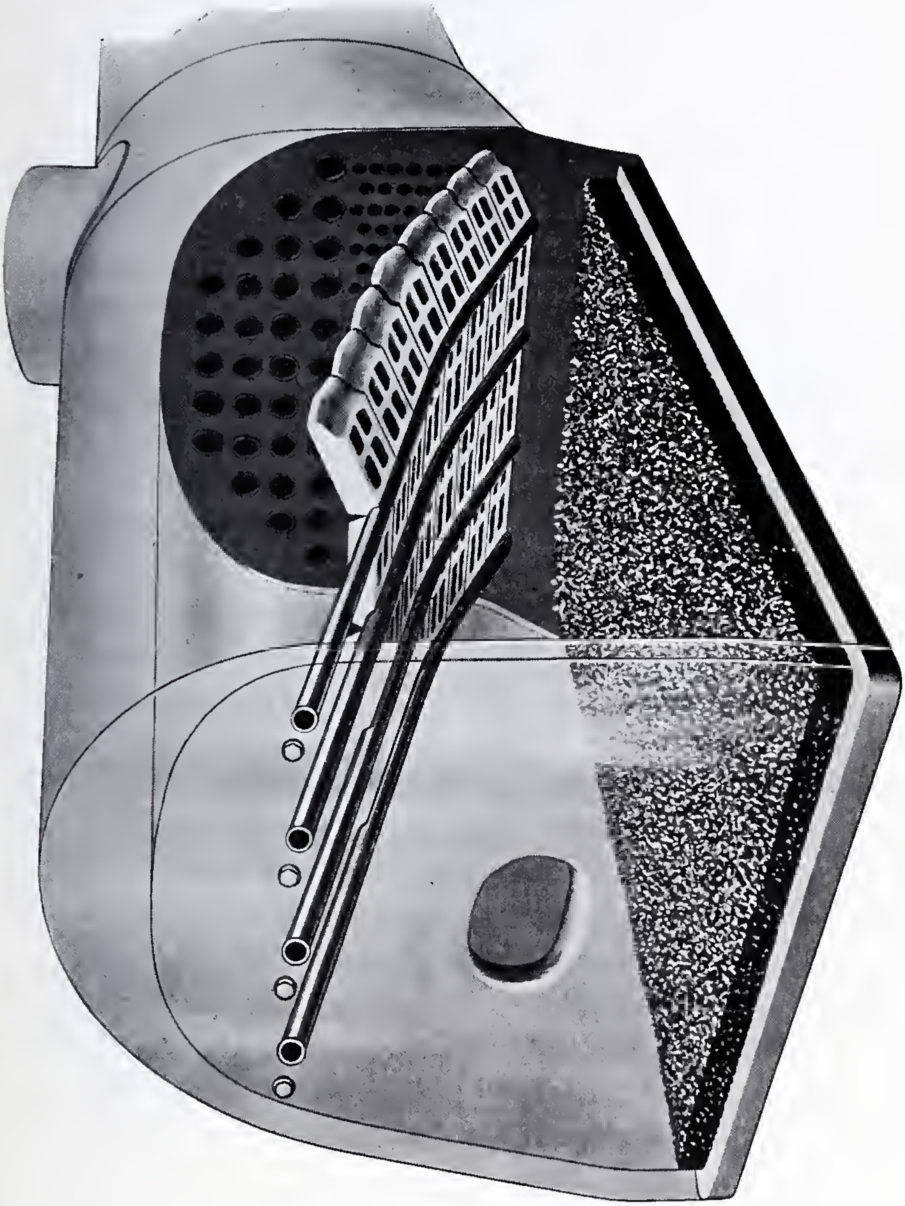

Fig. 2.—Phantom view of locomotive fire box with brick arch in place.

opening to the fire. On large locomotives in heavy service this function of supplying coal to the fire may be performed by mechanical stokers.

A significant detail of the modern locomotive fire box consists of the brick arch. This is also clearly shown in Figures 1 and 2. It slants upward from the front end of the furnace for about two-thirds the length of the box. It is made up of specially designed bricks which are laid upon three or four arch or water tubes running diagonally through the length of the fire box. This arch plays an important part in the combustion process, primarily because it helps to mix the products of combustion more intimately, lengthens the flame path in the fire box, and reflects considerable heat from the fire back onto the fuel bed. By virtue of this quality the brick arch also serves to reduce the fire-carrying capacity of locomotive sparks. It not only gives the spark-forming material a much better opportunity to burn itself out, but it also provides an opportunity for the mechanical breaking down of this material. An illustration of the locomotive fire box with arch in place is shown in Figure 2.

**5. The Smoke Box or Front End.**—The front end, or smoke box, is called upon to perform a vital service in the operation of the locomotive. It must be so arranged that it will create a strong draft of air through the fire in the fire box and then draw the products of combustion over the brick arch, out of the fire box and through the boiler tubes and flues, and finally discharge them through the stack out into the atmosphere.

The force or draft which pulls the air through the burning fuel bed and over the fire box and tube surfaces is created by the exhaust steam which is ejected by the engines through the exhaust nozzle in the front end. This exhaust nozzle, connected with the exhaust passages of the engines, discharges the exhaust steam directly into an extension downward of the locomotive stack. As it does this, the gases in the front end are entrained with it, thus creating a partial vacuum. This vacuum, however, is immediately broken by fresh gases of combustion

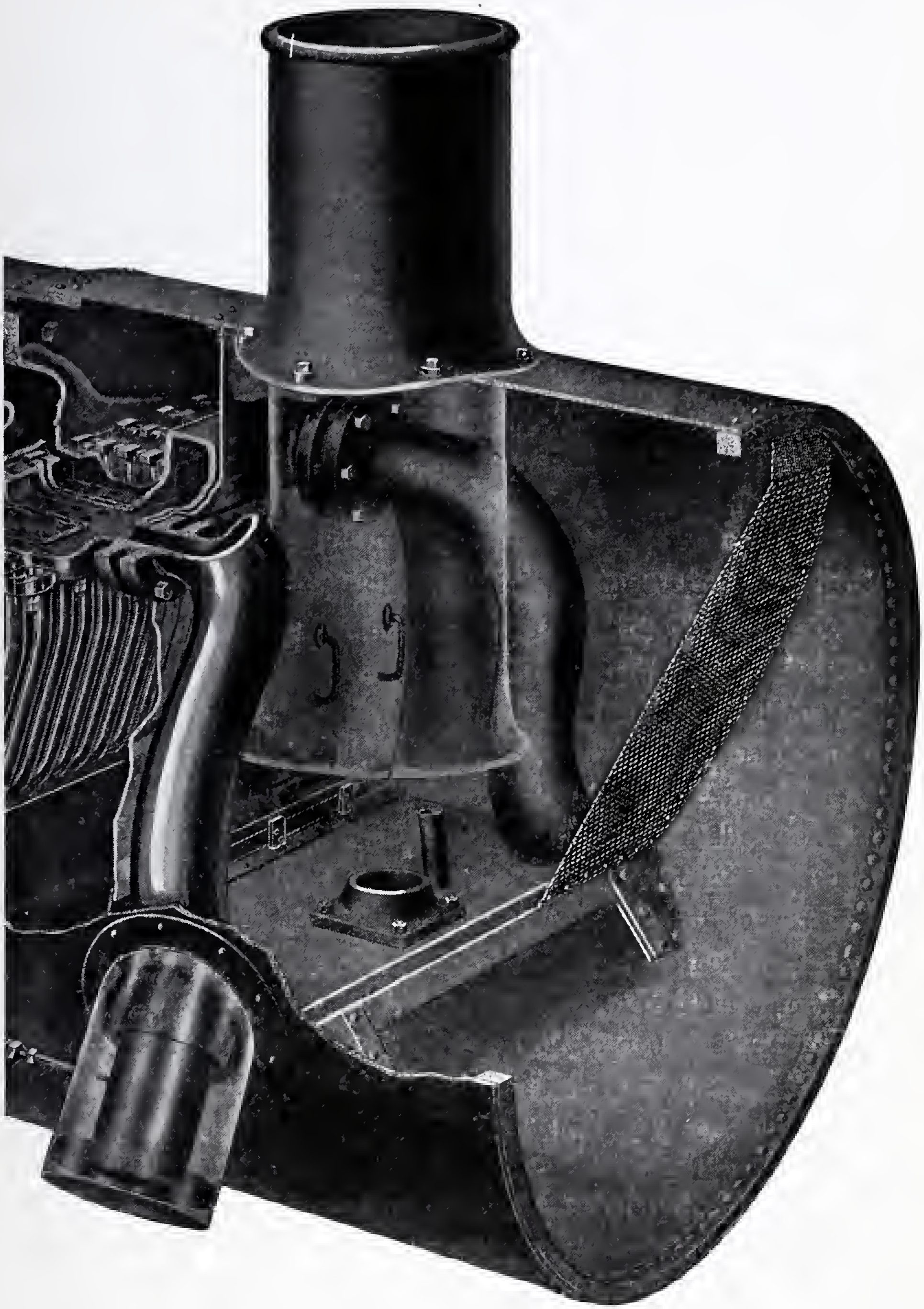

FIG. 3.—Locomotive front end on smoke box showing: the diaphragm or baffle sheet; and the front end netting.

rushing in from the fire box through the boiler flues and tubes. Thus as long as the engines are working, and hence the locomotive is moving, a draft action is set up through the fire, fire box, flues and tubes which keeps the process of combustion and heat transfer from gases to boiler water active.

However, while the front end arrangement is primarily delegated to set up the draft required for combustion, it also has a very important auxiliary service to perform. The products of combustion hold in suspension many relatively small particles of coal or spark material. The force which drags the fire box gases through the boiler must be very strong and continuous if the fire on the grates is to burn rapidly enough to supply the large amount of heat required for steam-making purposes. This force or draft moves the gases at such high velocity that they in turn pick up many of the lighter particles of fuel in various states of combustion and carry them out of the furnace, through the flues and tubes, and into the smoke box. If any come over which are too large, too hot, or still in an unburnt state—that is, are dangerous as fire carriers—they must be prevented from being discharged until they have been made harmless.

The modern locomotive front end is therefore equipped with two essential features which are designed to render these hot particles of fuel and ashes free from fire hazard. These features are, first, the front end diaphragm, or baffle plate and, second, the front end netting. A good idea of the location and way of working of these two provisions is conveyed by Figure 1. In addition, Figure 3, shows the front end and its detail parts, especially the baffle plate and netting. The diaphragm, or baffle plate has another important function to perform—that of distributing the draft action evenly over the grate surface. By thus inducing an even distribution of the draft action over the fire, a uniform combustion takes place. The likelihood of holes forming in the hot fuel bed is thus reduced, and so the tendency towards carrying spark material through the flues of it is also lessened.

The baffle plate further serves to deflect the spark particles issuing from the tubes and flues downward and away from the point of strongest exhaust action.

The combined influences of the draft inducing exhaust steam and the deflecting function of the baffle plate creates a cyclonic action in the front end. The cyclonic action breaks up and decreases in size the sparks that reach the front end by causing them to be violently impinged against the baffle plate, the sides and bottom of the front end, the exhaust pipes and the netting in the front end.

Such particles, however, as have escaped sufficient breakdown action while passing by the baffle plate must be prevented from escaping out of the stack. This is accomplished by interposing a screen or netting across the path of the exhaust gases after they have passed the baffle plate but before they finally enter the stack. Such a netting is clearly shown in Figure 3.

**6. The Ash Pan.**—The preceding description serves to point out the principal feature of the coal-burning locomotive which tends to make of it a special type of fire risk. However there is an additional feature of the locomotive which adds to this tendency. The solid wastes of combustion, that is, the heavy ashes and cinders which are formed on the grates, must be discharged from time to time into a special receptacle which is provided underneath the grates or fire box. Such a receptacle is known as the ash pan. It catches all the dirt, clinkers, cinders and ashes which are shaken down or passed through the grates, and prevents them from falling onto the track, ties, wooden bridges and trestles, or down side embankments where they may start fires. Ash pans are required, therefore, to be tight in their construction. Only when over special places such as ash pits may the ash pan doors or hoppers be opened and the furnace refuse discharged.

## CHAPTER IV

## THE LOCOMOTIVE SPARK ARRESTER

**1. The Front End Problem.**—A general description of the modern locomotive front end is found in Chapter III together with illustrations. Its functions, as already indicated, are twofold. First, the front end arrangement serves to establish a steady even draft through the fuel bed, fire box and flues of the locomotive, thus stimulating combustion and heat transfer. The action of this draft through the fuel bed, however, causes small particles of coal, in various stages of combustion, to be carried from the fuel bed under and over the arch, i.e. out of the fire box, and then through the boiler flues, under the baffle plate, through the netting, to be ejected finally from the stack. Because of this fact it becomes the added duty of the front end to reduce the fire-carrying capacity of these particles of coal to the very lowest limits and to reduce their size and the number ejected as well.

The locomotive spark arrester may therefore be defined as that part of an arrangement in the front end provided for the purpose of rendering locomotive sparks harmless or free from fire danger before it is ejected from the stack. The definition given by the Locomotive Dictionary is to the effect that the Spark Arrester is "a device placed in a locomotive smoke box for the purpose of preventing the throwing of live sparks from the stack."

The most practicable way which has been devised thus far to reduce the fire-carrying danger of locomotive sparks has been, first, to retard the ejection of the sparks until they have burned themselves out, and, second, to reduce them in size and number so that their fire-carrying capacity is small and hence not dangerous. The necessity for providing means for this purpose conflicts directly with the draft-creating function of the front end. Considered in another way, the spark prevention features of the front end place an added burden on the draft-inducing apparatus proper. Consequently, ever since the construction and operation of locomotives it has been a problem how to design and arrange the front end so that both requirements may be fulfilled without unduly limiting the economy, efficiency and usefulness of the locomotive, while at the same time maintaining the highest possible safety factor.

**2. The Development of the Front End.**—The historical development of the front end is of interest because it really shows how difficult it is to harmonize the two basic but conflicting functions mentioned above. Several excellent summaries[1] covering the history of the front end have been prepared, hence it will not be necessary here to make many detailed repetitions. A brief survey will, however, be of value.

It appears that the front end used on early American locomotives was similar in type to that used on locomotives[2] in England. Mr. J. Snowden Bell describes this front end as follows:

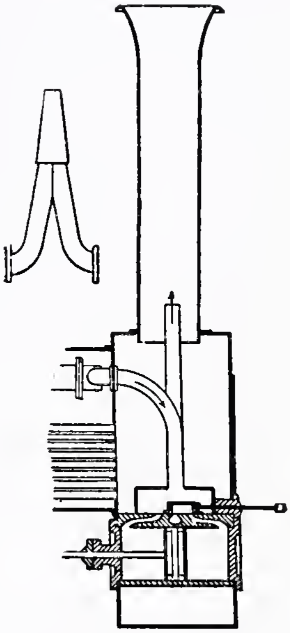

FIG. 4.—Very early type of front end.

Reproduced from an article by J. Snowden Bell, Proceedings, Western Railway Club, V. 12, 1899–1900, p 7.

> "The smoke box was of D shape in cross section, and had a straight open stack. The steam and exhaust pipes were carried to and from the cylinders, inside the smoke box, as in present practice, and the exhaust nozzles were usually double and high. The cylinders were attached to the bottom of the smoke box, if a crank axle was used,

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[1] Report of Committee on Locomotive Front Ends, *in* Proceedings of the American Railway Master Mechanics' Association, 1906, p. 237.

J. Snowden Bell, "Locomotive Front Ends," *in* Proceedings, Western Railway Club, 1899–1900, pp. 7–55.

W. F. M. Goss, "Locomotive Sparks," Chapter IV.

[2] J. Snowden Bell, Ibid., p. 7.

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or to the sides, in outside connected engines. No special draft appliance or spark arrester was used. Figure [4], which is reproduced from Plate 2 of 'Pambour's Practical Treatise on Locomotive Engines,' American Edition, 1836, illustrates all the essential features of the earliest type of front ends. Apparently as a matter of mere mechanical convenience, and without any rule or basis as to its volume or capacity, the smoke box was made about the same length as the cylinders, and this continued to be the universal practice until the advent of the lengthened or extended smoke box, or so-called 'extension front,' in 1859."

The arrangement of details in this form of front end, provided no adequate means for preventing the discharge of fire carrying sparks. The development of this feature followed later, when the danger of sparks from locomotives became more and more evident. The first attempts to meet this hazard were simple, amounting to the provision of a cap of netting over the stack for the purpose of intercepting the large, fire-carrying sparks. This idea in turn suggested the addition of an inverted deflector over the top of the stack for the purpose of segregating the heavier particles and casting them downward again into the stack. The underlying theory of this improvement was that the bigger particles would thus be gradually worn down in size and reduced in ignition danger. Suffice it to say that these early attempts to solve the problem proved to be along substantially correct and feasible lines. It was on the basis of facts and tendencies which these attempts revealed that the balloon stack (Figure 5) and eventually the successful diamond stack (Figure 6) were developed.

It was in 1833[1] that the first description appeared of the use of a spark-arresting appliance in the front end proper. This appliance, as described by J. McIlvaine, consisted of a sheet or wire netting extending in an inclined position entirely across the smoke box from the top of the front flue sheet to the bottom forward end of the smoke box. The exhaust pipe and steam pipes passed

[1] Journal of the Franklin Institute, Vol. XII, New Series, 1833, pp. 74–77.

through it. Its purpose was two fold to help distribute the draft properly over the fire, and to suppress any large sparks.

The means necessary to distribute the draft properly through the flues and over the fire surface were developed very early and practically coincident with the development of the spark-arresting features. The ways then found to be most effective still prevail on the modern locomotive. These are the deflector plate and the "petticoat" or draft pipe. This latter detail has on many modern locomotives evolved into the "smoke stack extension." The union, as it were, of the "petticoat pipe" with the smoke stack into a single casting is simply a mechanical improvement, not the introduction of a new principle.

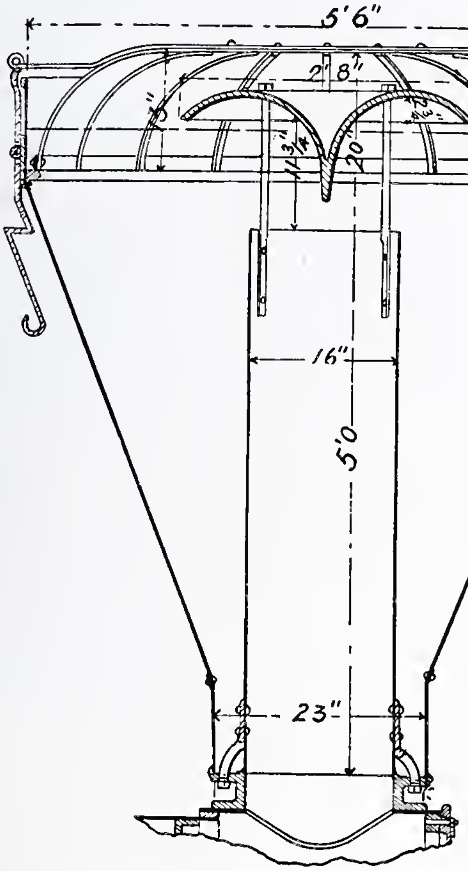

Fig. 5.—Balloon stack.

Naturally the placing of netting in the front end together with the draft distributing plates, suggested a simplification of the whole front end and stack arrangement. Thus the way was paved for the removal of the relatively complicated spark-arresting appliance placed in the stack which had evolved into

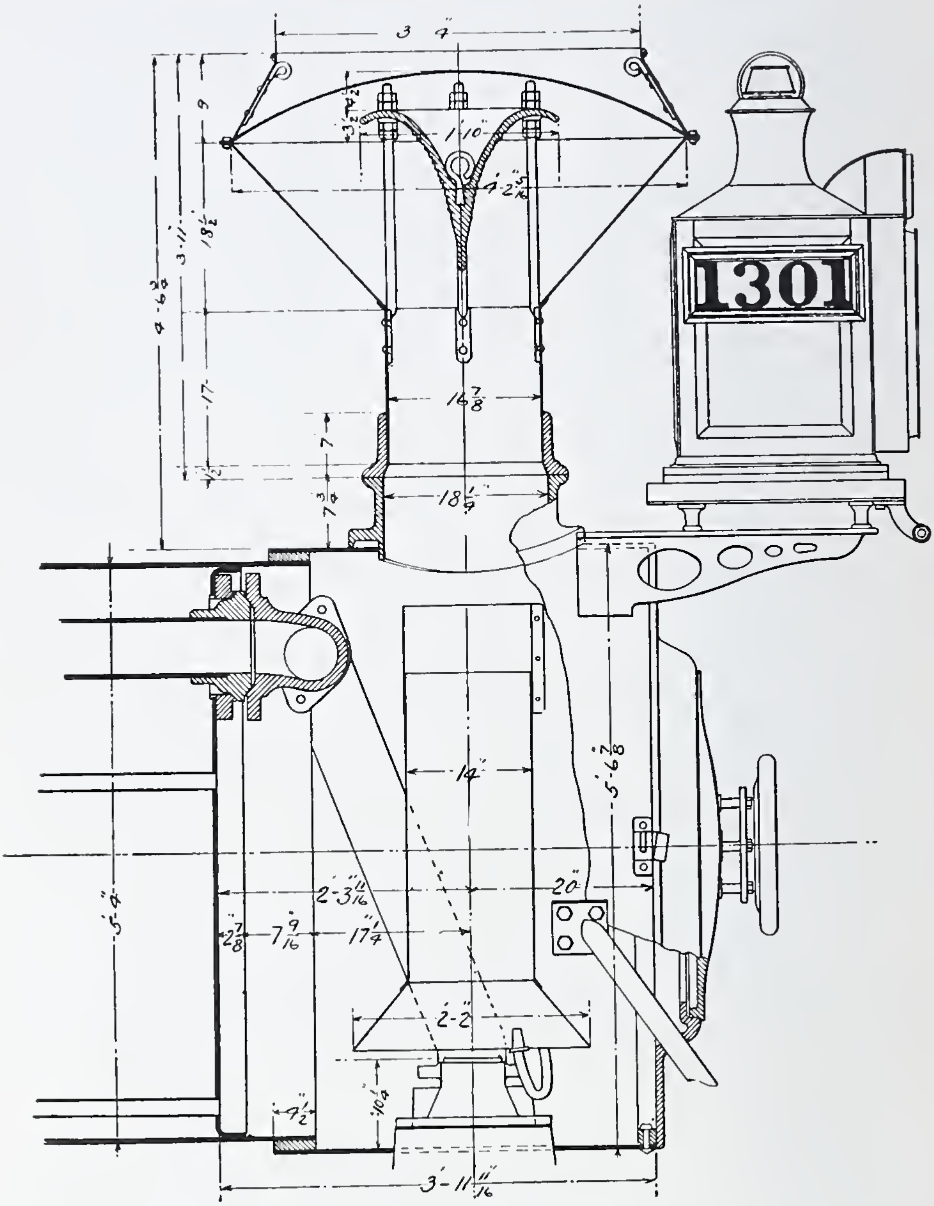

Fig. 6.—Diamond stack.

the successful diamond stack already referred to. The stack became comparatively straight and simple in construction. Netting was stretched either horizontally or slantingly across the path of the gases, extending usually from the deflector sheet forward. Two such typical netting arrangements employed for spark prevention in coal burning locomotives are illustrated in Figures 7 and 8 respectively.

One interesting attempt to reduce the number of sparks escaping from the front end was made when the smoke box was extended forward or lengthened out so as to provide additional volume ahead of the deflector plate, exhaust nozzle, and smoke stack. The theory was that this additional volume would act as a "dead" space into which the spark material would settle and thus not pass out of the stack. In order eventually to remove the material from this space, an opening was provided at the bottom In practice, however, it was found that the provision of this extra front end volume was more of a detriment than an advantage. Not only did it actually permit of the accumulation of some spark material which had to be removed on the road and thereby frequently interfered with the expeditious movement of the locomotive; but the volume of sparks actually ejected under these conditions was only slightly reduced. In other words, no front end could be designed with capacity large enough to be at all effective in storing spark material sufficient to reduce the amount ejected to any appreciable extent.

**3. Front End Standards.**—It was not until 1901 that systematic efforts were made to study the locomotive front end scientifically. At that time the American Engineer and Railroad Journal, now the Railway Mechanical Engineer, entered into a coöperative arrangement with Purdue University for the purpose of conducting a series of experiments on locomotive front ends. The Committee on Locomotive Front Ends of the American Railway Master Mechanics' Association, subsequently coöperated with Purdue University and the American Engineer and Railroad Journal, and submitted a very valuable and historic report on the

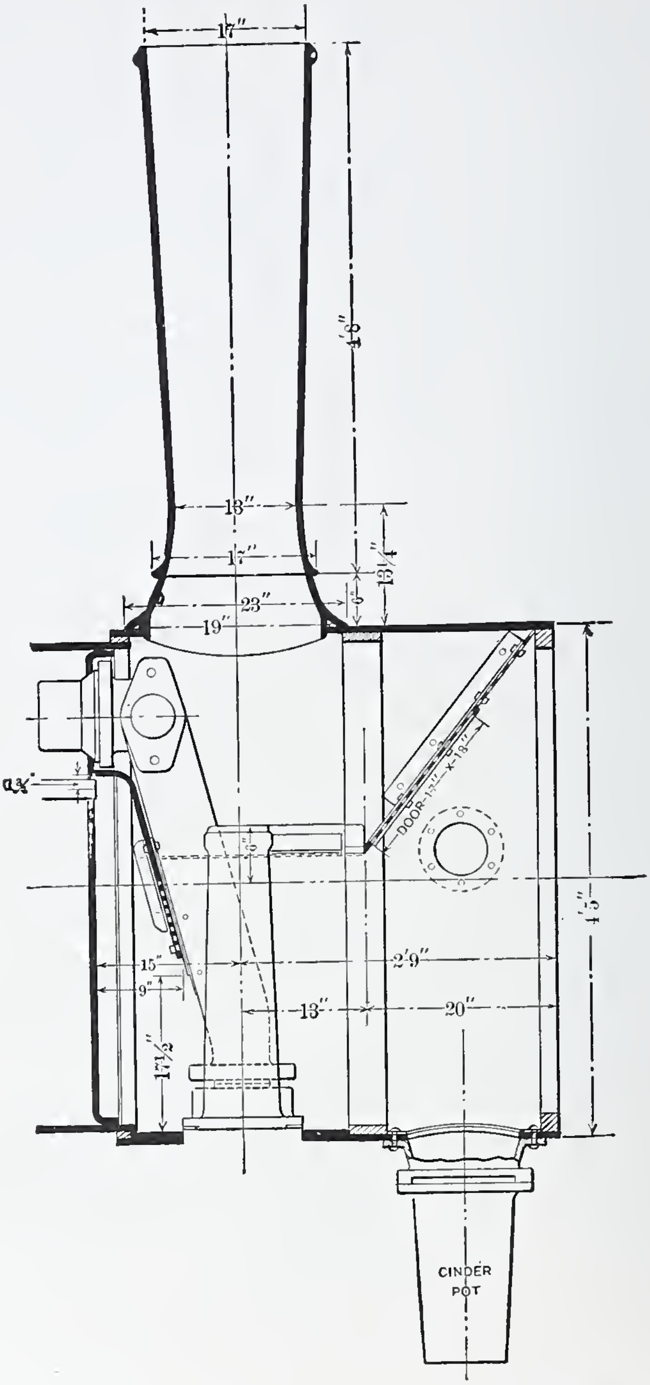

Fig. 7.—Early type of netting arrangement employed for spark prevention in coal burning locomotives.

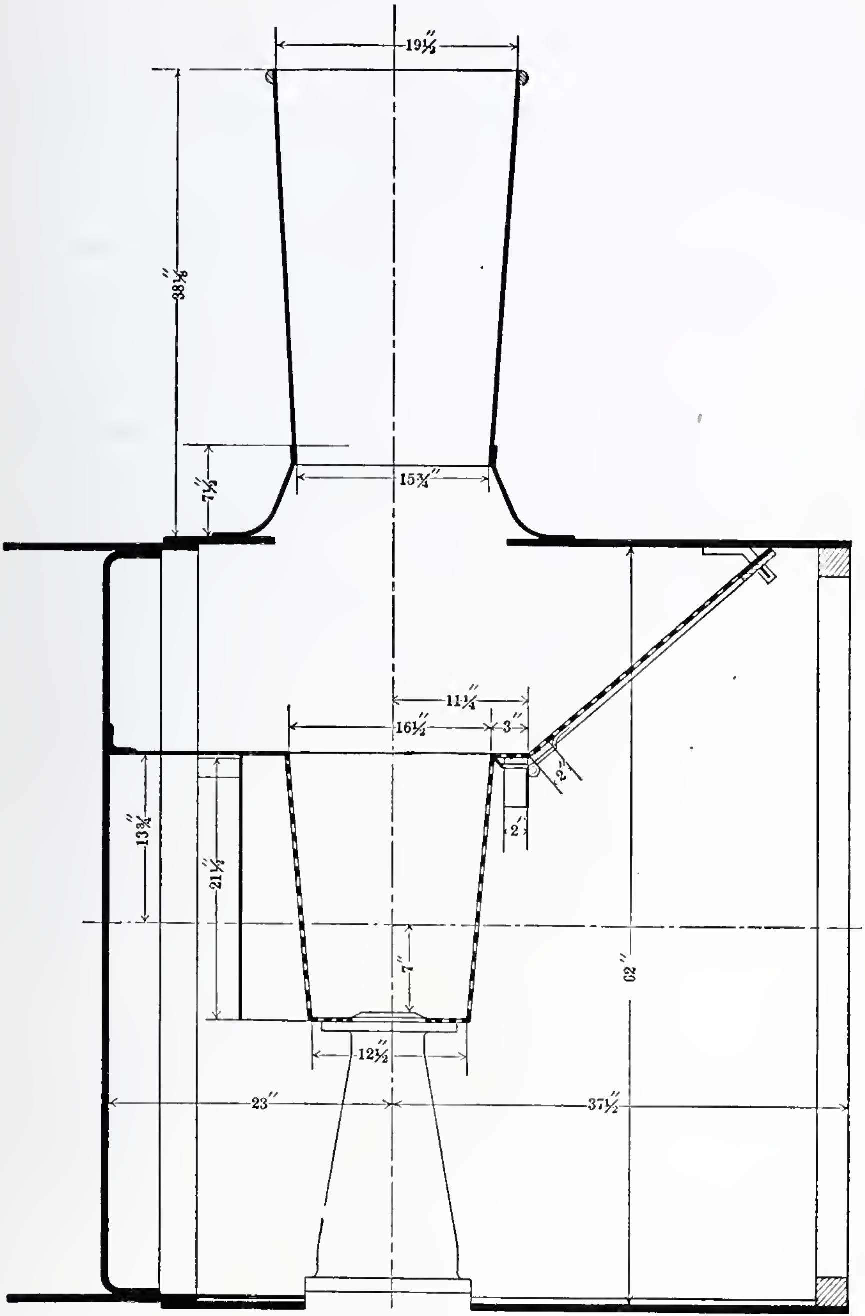

Fig. 8.—Early type of netting arrangement employed for spark prevention in coal burning locomotives.

locomotive front end, to the American Railway Master Mechanics' Association in 1906.

The results of these experiments enabled the submitting of suggestions for standard front end proportions. These suggestions, however, were confined primarily to the draft function of the front end and not to the spark eliminating function. The detail arrangements necessary to properly regulate the draft are subject to fewer varying influences than the arrangements necessary to control spark ejection. This fact is obvious when it is considered that the early arrangements of deflection plate, exhaust nozzle, petticoat pipe and smoke stack are used to this day, with only relatively simple mechanical modifications. The contributions, as summarized in the report of the Committee on Locomotive Front Ends of the American Railway Master Mechanics' Association, was the establishment of standard draft arrangement proportions which permitted the general design for the so-called Master Mechanics' front end as adopted by most railroads of the country. A typical illustration of such a front end applied to a saturated steam locomotive in general operation about fifteen years ago is shown in Figure 9.

**4. Modern Locomotive Front Ends.**—The advent of the locomotive superheater and to a certain extent the mechanical stoker has largely made possible the operation of the modern high power locomotive. When the experiments were made which led to the suggestion of the "Master Mechanics'" front end proportions, the existing standard locomotives on the average were only about half the power and weight of the modern heavy duty locomotive. The location of the superheater header in the front end, together with the necessity for shutting off the draft through the large superheater flues when the engines are not working steam, have introduced a complication into an otherwise simple standard front end arrangement. A typical arrangement of the front end of a recent Mikado locomotive is shown in Figures 1 and 3, Chapter III.

The larger the locomotive becomes, the greater in proportion is the amount of fuel consumed. This fact in itself would seem to

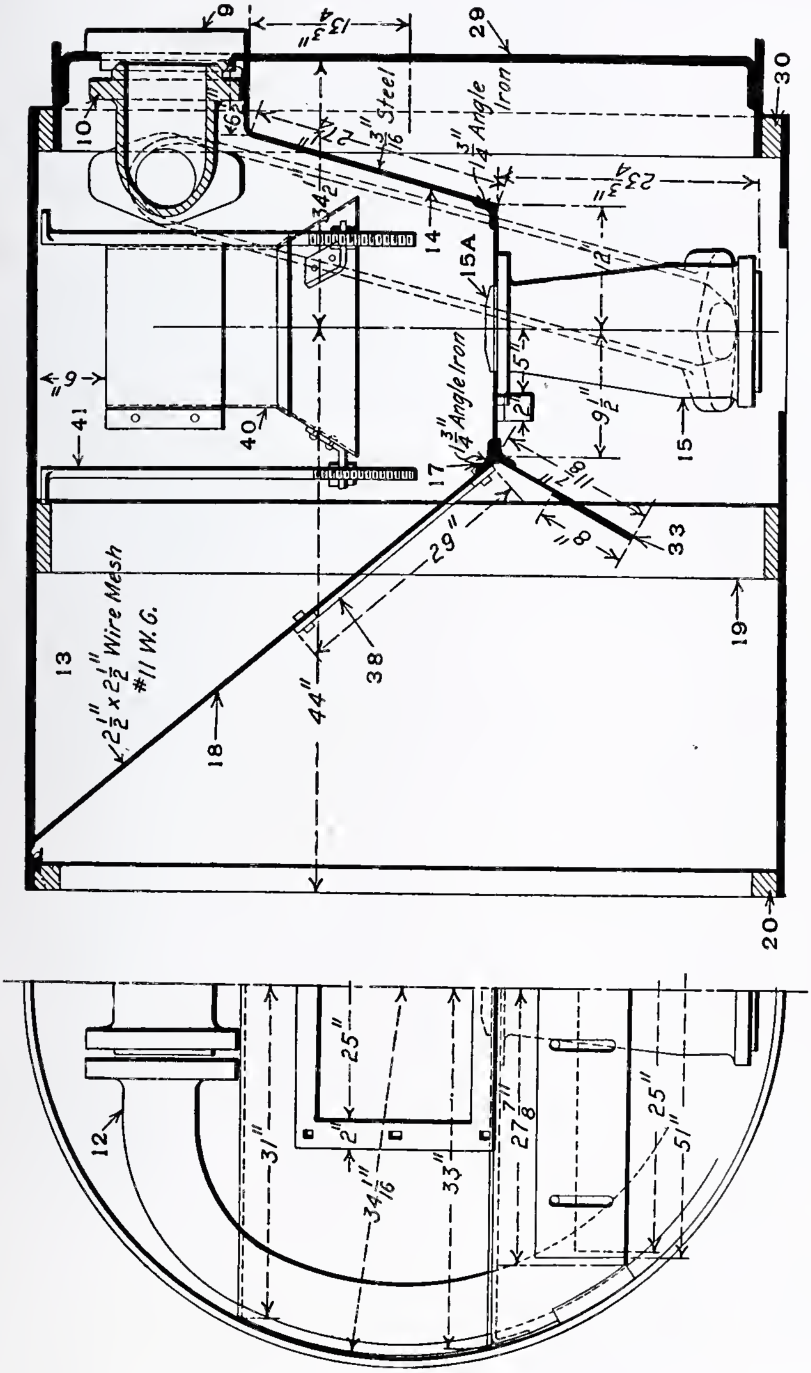

FIG. 9.—Typical illustration of Master Mechanic's front end applied to a saturated steam locomotive in general use about 15 years ago.

be partially responsible for the increasing attention which is being paid to the locomotive as a fire liability. Certainly the greater the amount of fuel burned in the locomotive fire box, the greater the amount of spark material which must eventually be ejected from the stack. The modern locomotive therefore intensifies the necessity for devising ways and means for keeping the spark risk within safe limits.

As a general proposition, the efforts made to meet the situation precipitated by the large modern locomotive falls into two classes. Efforts of the first class aim at reducing or mechanically wearing down the sparks by attrition. This is attempted by the introduction of additional physical obstructions against which the sparks impinge, or as a result of which they are violently agitated, and thus are broken or worn down. Efforts of the second class aim at preventing, by means of improved nettings, the ejection of sparks above a limited size. To be sure, nettings also assist in wearing down sparks by holding them in a confined space while the cyclonic action within the front end drives them hither and thither against the normal obstructions present as well as against each other, so that they are finally worn down to ejectable size.

**5. Recent Spark Arrester Improvements.**—There are but few improved spark arrester arrangements in actual service which employ extra methods for wearing down the sparks mechanically. As a rule such extra methods have not justified themselves. In general the ordinary arrangements of deflector plates, steam pipes and nozzle stand, together with the superheater pipes, header, and damper plates, as well as the walls of the front end, provide sufficient obstacles to serve as wearing and agitating surfaces.

The Philadelphia & Reading Railway Company, however, has been experimenting with a special arrangement designed largely for spark abrasion. It has been termed the Economy Spark Arrester. This type of arrester as applied to a modern superheater locomotive is illustrated in Figure 10. The super-

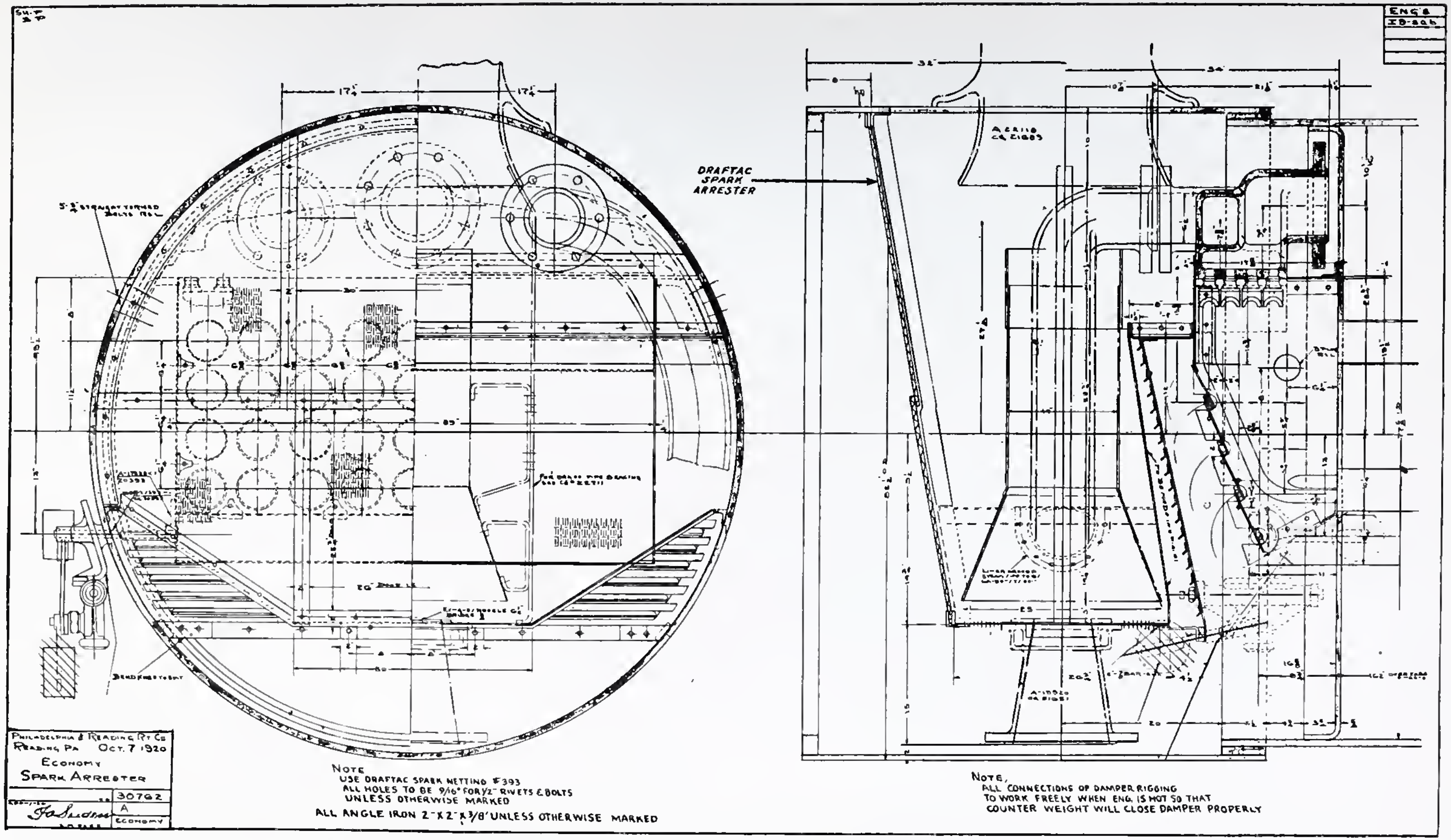
DRAFTAC SPARK ARRESTER
Philadelphia & Reading Ry Co
Reading Pa Oct. 7 1920
Economy
Spark Arrester
30762
A
Economy
NOTE
USE DRAFTAC SPARK NETTING #393
ALL HOLES TO BE 9/16" FOR 1/2" RIVETS & BOLTS
UNLESS OTHERWISE MARKED
ALL ANGLE IRON 2" X 2" X 3/8" UNLESS OTHERWISE MARKED
NOTE,
ALL CONNECTIONS OF DAMPER RIGGING
TO WORK FREELY WHEN ENG. IS HOT SO THAT
COUNTER WEIGHT WILL CLOSE DAMPER PROPERLY
17¼"
17¼"
32"
34"

FIG. 10.—Philadelphia and Reading Railway Company's Economy spark arrester as applied to a modern superheater locomotive.

heater damper door consists of four separate pieces of sheet steel so arranged as to open out horizontally when steam is passing through the superheater to the cylinders. Immediately ahead of these damper doors, and extending downwards and slightly backwards from above the middle of the front end to approximately the level of the top of the nozzle stand, is an open framework of obtuse shaped angle bars, which extends completely across the interior and encounters a large portion of the products of combustion as they rush from the superheater damper box and the upper two-thirds of the small flues. This arrangement of angle bars serves the double purpose of deflector plate and mechanical destroyer of sparks. In addition this spark arrester provides an extra netting immediately in front of the angle iron framework as well as a perforated table plate. The usual slanting netting in the very front of the box is also used.

The special features of this spark arrester are stated to be as follows:

1. The table plate to sides of smoke box is at an angle to prevent collection of dirt; all fine particles are carried to the bottom of square part of table which is perforated so that the exhaust gases rushing through these perforations will carry accumulated particles up the stack.
2. The table plate is not fitted around the exhaust nozzle but rests on a flange provided at the top of the nozzle tip, below the table plate, thus avoiding large spark leakage.
3. It is a self-cleaning front end and only fine particles of dirt are discharged from the stack.

In addition, certain maintenance as well as draft operating advantages are claimed for it.

While this type of spark arrester has not been widely used, and, is still in the experimental stage, yet its consideration is of significance for it tends to show the direction in which efforts are being made to solve the locomotive spark problem.

Another type of special modern spark arrester is the Mudge-Slater. This arrangement, while of special design and construction, in reality is a simplification of the whole front end mechanism.

The Mudge-Slater spark arrester, which is illustrated in Figure 11, consists of a removable box the two sides and front of which are sheets of netting, and the back, top, and bottom of which are steel plates. This box is so arranged that it can easily be taken out through the front end door when repairs of an unusual nature must be made. It is readily seen that so simple an arrangement

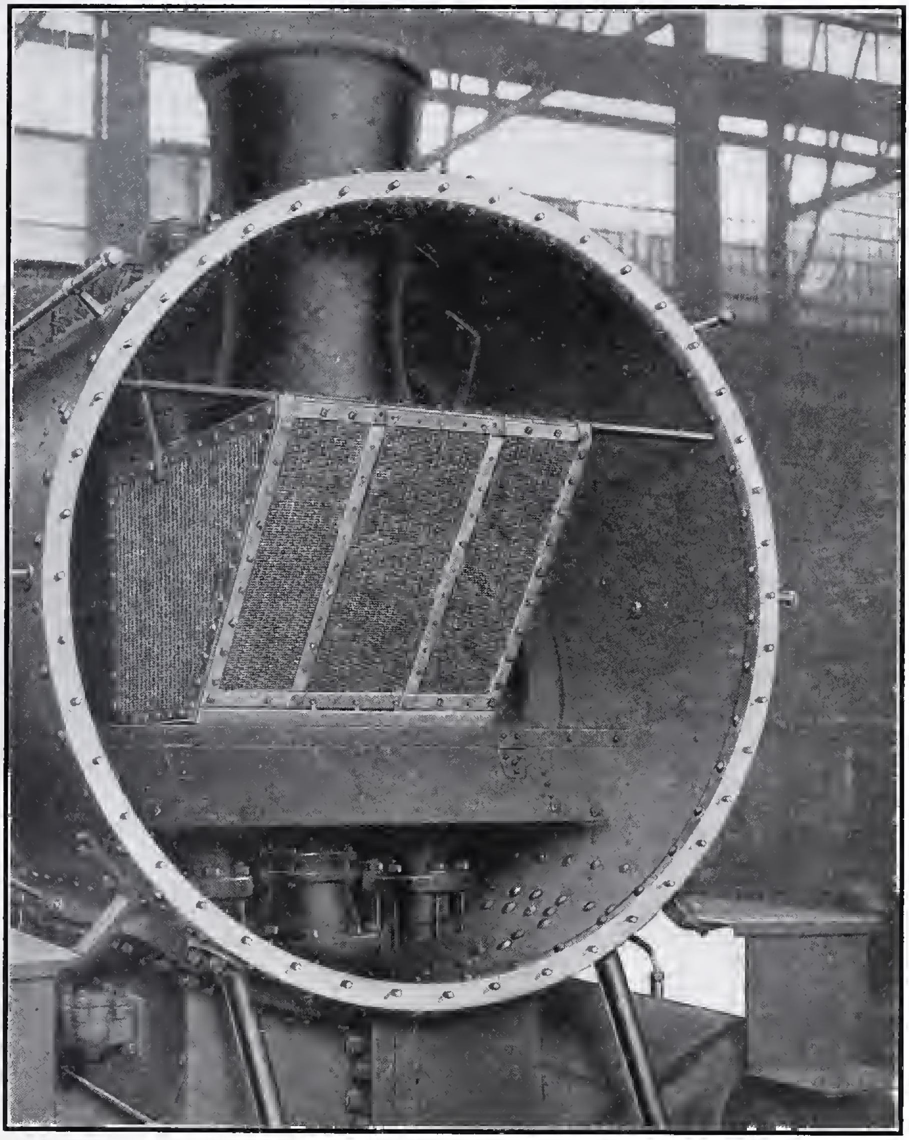

Fig. 11.—Mudge-Slater type of spark arrester.

of details, especially affecting the netting features, has advantages from both the inspection and maintenance standpoints.

**6. Spark Arresters for Special Conditions.**—The steadily mounting cost of railway fuel is placing a premium more and more upon the use of lower grade fuels such as sub-bituminous and lignite. This is particularly true on railroads which are long distances from bituminous coal mines, but along whose lines are found these inferior coals. The roads in the Northwest are in this class.

These poorer fuels are high in moisture content and volatile matter and usually low in heating value. Their physical characteristics, however, are such that they create a special spark problem when burned in the locomotive fire box. When used, the draft must be considerably increased. This fact, together with their extreme friability, their tendency to disintegrate mechanically into light, flaky particles upon moderate weathering, as well as the absence of coking properties, causes the formation of large volumes of sparks. It is the control of these sparks which presents a special spark arrester problem for the front ends of sub-bituminous and lignite burning locomotives.

A committee appointed by the International Railway Fuel Association to investigate the subject of sub-bituminous and lignite coal as locomotive fuel submitted a comprehensive report on the subject in 1913.[1] Those concerned with the spark difficulties created by these fuels, will find the report of this committee of great value.

There are still a good many locomotives in use, especially on lumber railroads, which depend on wood for fuel. As already pointed out, wood, owing to its light weight, but more particularly owing to its tendency to burn easily with a distinct flame, presents a spark prevention problem similar to that of sub-bituminous and lignite coal. Hence it is necessary to provide wood-burning locomotives with more or less special spark-arresting devices as distinguished from ordinary coal-burning

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[1] Fifth Annual Proceedings, International Railway Fuel Association, 1913.

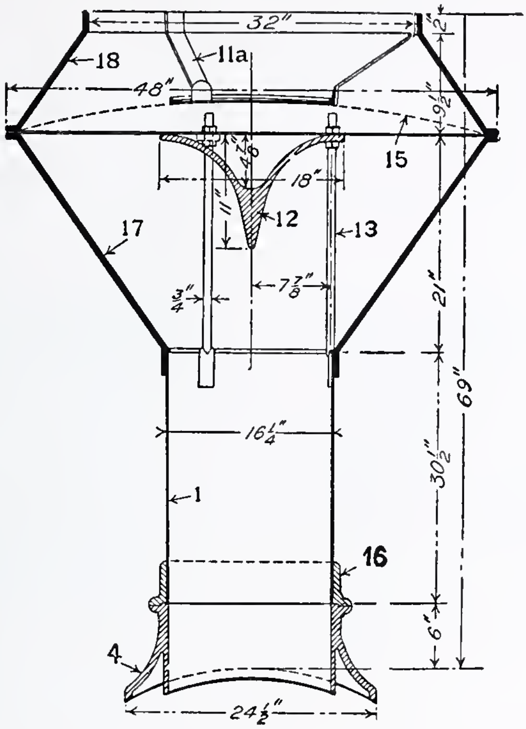

FIG. 12.—Early front stack arrangement screens—designed for service with wood as fuel.

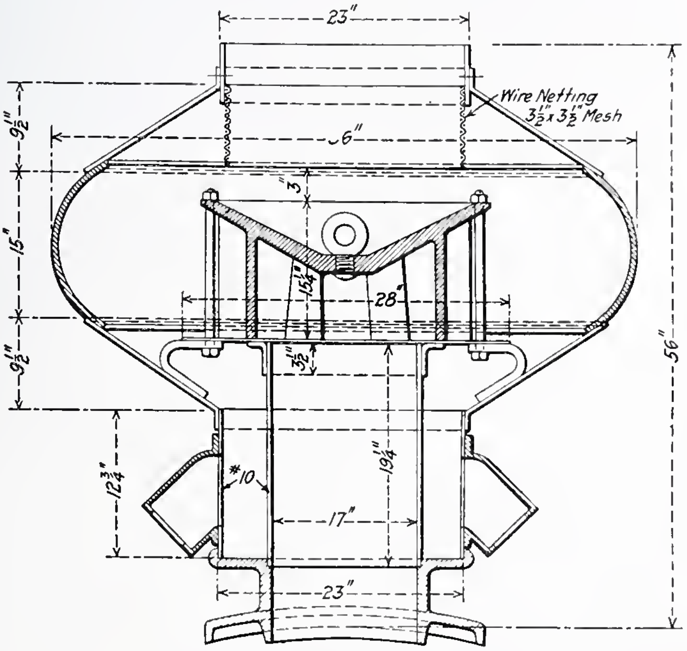

FIG. 13.—Radley and Hunter smoke stack for wood burning locomotives.

locomotives. These devices are usually placed at the top of the stack. Their design, as employed today, closely follows the former diamond stack construction. In fact, one type, illustrated by Figure 12, conforms to this exactly. An attempt to improve the more simple diamond stack arrangement is illustrated in Figure 13. This design is known as the Radley and Hunter smoke stack for wood-burning locomotives.

**7. Spark Arrester Netting.**—It has become quite evident that the employment of netting in the front end is the most effective way of controlling the spark danger of the locomotive. All the other special details intended to help in this direction have proved more or less unsatisfactory. It is upon the front end netting, that the main reliance for spark prevention must be placed.

In the selection of netting for spark prevention purposes, two factors have naturally governed. The netting openings or "mesh" had to be small enough to prevent the emission of sparks of dangerous size; while the wire strands of the netting had to be heavy enough to stand the wear and tear of front end service. In a given opening the larger the diameter of the netting wire, the less the available draft area through the netting.

A square mesh netting, 2½ × 2½ mesh per inch, with a wire diameter of .135 inch has clear openings of .265 inch × .265 inch, which gives a draft area of 43.9%. Figure 14 illustrates netting of this size. Sometimes netting is used of a slightly finer mesh for instant, 3 × 3 mesh per inch, with a wire diameter of .135 inch. The openings through this finer netting are .198 inch square and the draft area is reduced to 35.3%.

It is apparent from the foregoing that the draft area of the netting is a feature which must be taken seriously into consideration. This is desirable for the sake of freedom of draft as well as for preventing the clogging of the netting. If the openings through the netting are too small the netting will gradually clog and the front end fail to clean itself. And finally the free burning of the fire will be interfered with, for draft action, under such conditions, will degenerate.

The tendency towards limiting the draft area of the finer netting screens can be partially overcome by providing additional screen area. This, however, introduces not only construction difficulties but also maintenance and inspection difficulties. Hence this alternative has not been found practicable in the long run.

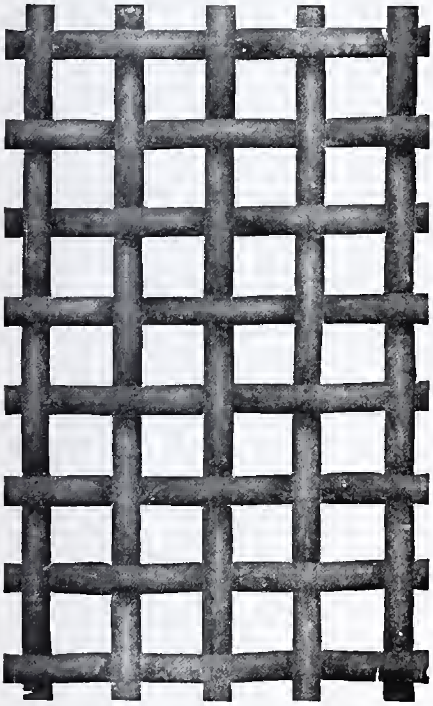

Fig. 14.—Square mesh netting, 2½ by 2½ mesh per inch; Openings .265 inch by .265 inch; Draft area 43.9 per cent.

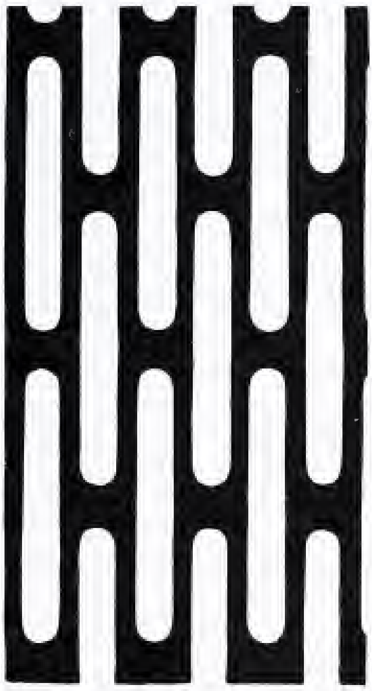

Fig. 15.—Perforated steel plate used for spark arresting purposes; Openings 3/16 inch by 1½ inches with ⅛ inch bridges; Draft area 47.7 per cent.

The 2½ × 2½ square mesh netting has left much to be desired, especially when fire hazard conditions seemed to make it desirable to use netting of a smaller mesh. This has prompted attempts to develop improved types of netting which would not make it necessary to sacrifice draft area for the sake of keeping down the size of sparks.

It was with this object in view that perforated steel plates were suggested and tried in place of the ordinary square mesh netting. The type of plate most commonly used is shown in Figure 15. It will be noted that the holes are relatively long and narrow. Their dimensions are usually 3⁄16 inch × 1½ inch with ⅛-inch bridge between. The plates themselves are usually ⅛ inch thick.

The difficulties experienced with this type of screen are mostly those of maintenance. In the first place, owing to the square sections of the bridges and the sharp edges of the perforations, the sparks passing through quickly wear away the bridges and enlarge the holes. Then again, the mechanical make-up of these perforated sheets is such that they cannot stand much stretching. In other words, they are weak, especially in a cross-tension direction, so that the holes tend to pull open, thus enlarging the area through which sparks might escape.

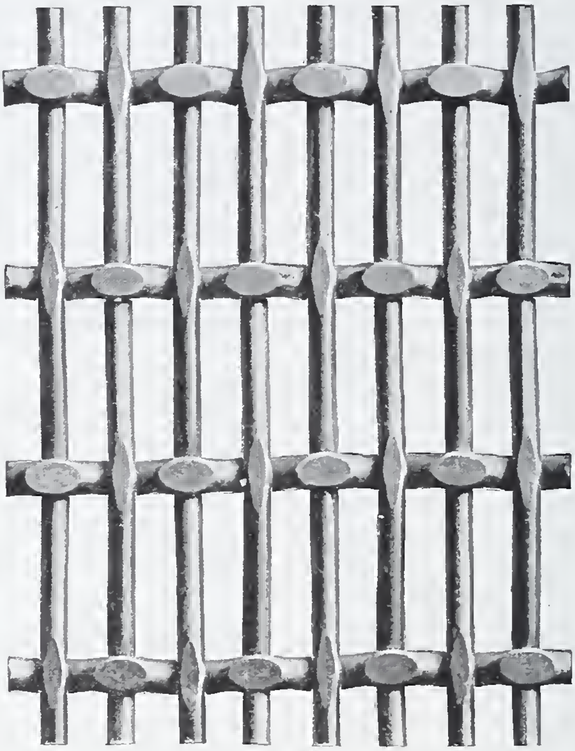

Fig. 16.—Oblong mesh netting known as Draftac. Openings 3⁄16 inch by ¾ inch; Draft area 49 per cent.

A consideration of the foregoing two types of netting, together with their limitations and weaknesses, led to the development of

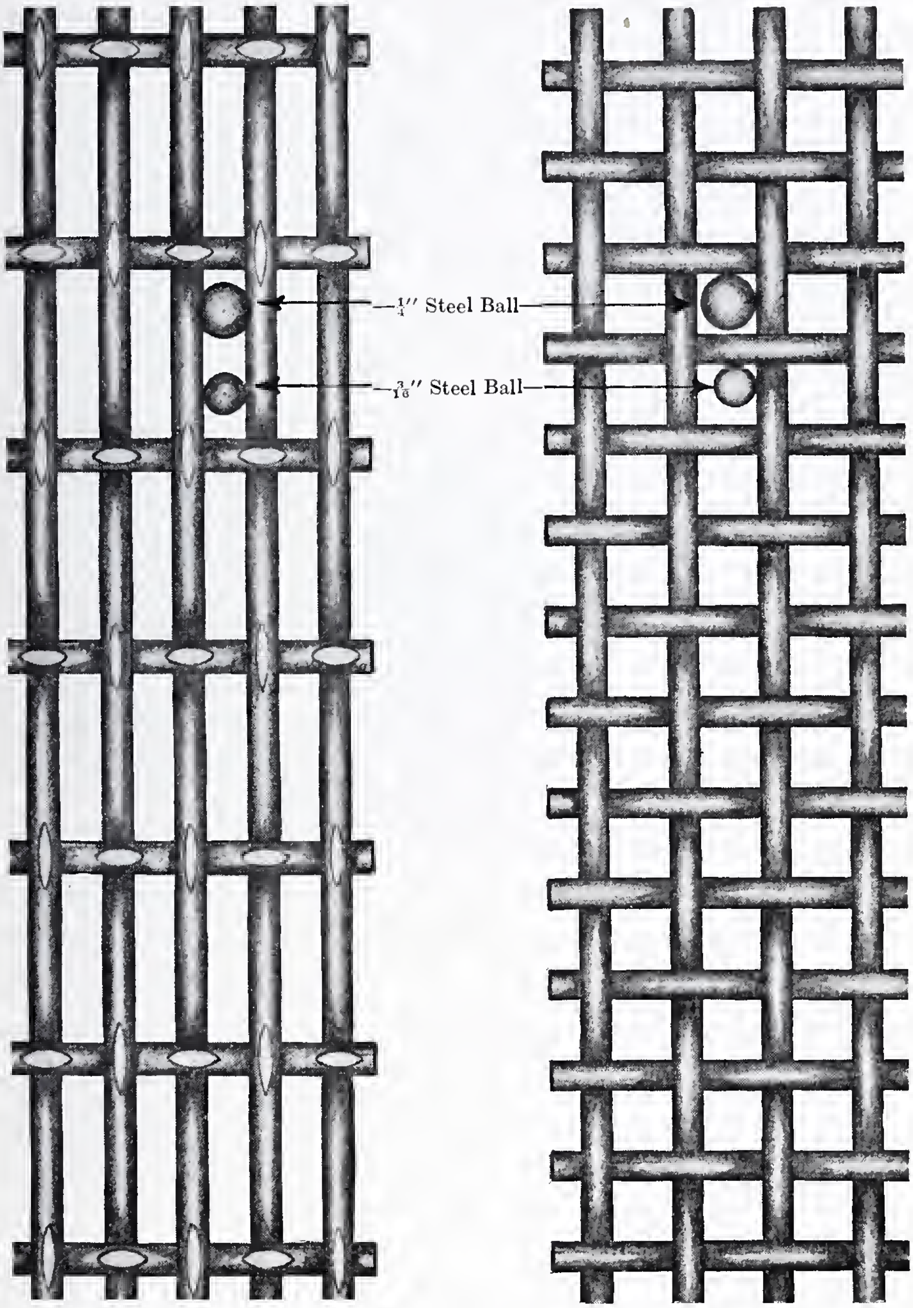

Fig. 17.—Comparison showing ¼ inch (.25 inch) and 3/16 inch (.188 inch) steel balls in relation to the openings of oblong mesh or Draftac and square mesh netting in common use as spark arresters.

a netting which combines the strength and durability of round wire square mesh netting with the increased draft area advantage of the perforated plate. Thus it has been found practicable to perfect a wire netting with oblong openings 3/16 inch × 3/4 inch in size and with strands .135 inch in diameter, or the same size as that used in the ordinary square mesh netting. Thus the draft area of the netting as compared with the common 2½ × 2½ square mesh netting is increased from 43.9% to 49%. At the same time, the largest thickness of sparks which will pass through the oblong opening is less by over 1/16 of an inch, i.e., actually .0775 inches. An illustration of this type of netting known as Draftac is shown in Figure 16. Figure 17 shows clearly how the openings through 2½ × 2½ inches square mesh netting compare with the openings through 3/16 × 3/4 Draftac netting. The larger steel balls, i.e., those 1/4 inch in diameter will pass through the square mesh netting but no ball larger than 3/16 inch in diameter can pass through Draftac netting. This gives an excellent idea of the relative effectiveness of these nettings in keeping down the size of locomotive sparks which escape from the stack.

**8. Spark Arrester Construction and Maintenance.**—The mechanical construction of the spark arrester has a great deal to do with the efficiency of spark prevention. If the construction is complicated, the parts inaccessible, difficult to remove or to inspect, the chances of dangerous spark ejection obviously become greater. A clear recognition of this fact has resulted in the concentration of special attention upon the problem of spark arrester design and construction from this point of view.

The Mudge-Slater, or Box spark arrester, has already been described. Its advantages result principally from the fact that it is a decided improvement from the construction, inspection and maintenance standpoints. Not only is this arrester so arranged that it can be easily inspected when in place, but it can also be removed with convenience and despatch. It is so constructed that the entire box is first assembled on the floor and then set in place between the nozzle stand top and the bottom of the smoke stack extension. By virtue of its compactness and ease of handling it enables a greater convenience in doing work on the flues.

However, the ordinary spark arrester arrangement has been found to be amenable to some simple and effective improvements in construction. For instance, the practice of applying the spark arrester netting in one piece with a very small center door, as illustrated in Figure 18, was quite generally followed until rather recently. This resulted in waste when cutting the netting from a roll of standard width. It also necessitated the removal of the front end ring to get it into place, or else this large piece had to be bent and rolled up so as to pass through the front end door and then straightened out inside the smoke box and bolted into place. Naturally such punishment has a certain deteriorating effect on the spark-preventing qualities of the bent and restraightened netting.

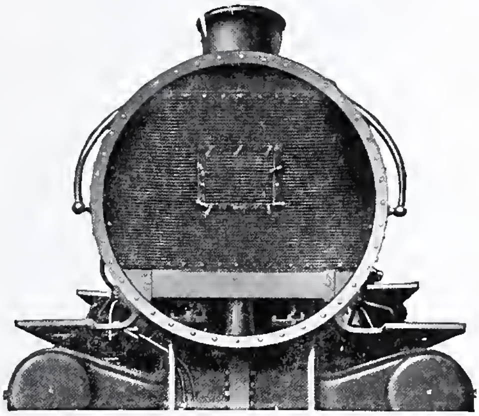

Fig. 18.—Spark arrester netting installation in one piece with a small center door.—Uneconomical.

The undesirability of such a practice has recently been recognized so that now the spark arrester netting in many cases is made in three pieces as indicated in Figure 19. Not only does this save unnecessary work and punishment of the screens when being put into place, but it also results in economy. For it is found that the center of the netting wears out by spark abrasion about twice as fast as the sides. By the three-piece system the useful life of about two-thirds of the netting is thus practically doubled.

The matter of constant, regular front end inspection is of the very greatest importance if the danger of large spark ejection is to be kept under control. As indicated in Chapter II, the burden of fire prevention falls directly upon the railroads, and by the implications of the statute laws as well as the common law, the railroad managements are obliged to take every reasonable step to reduce the likelihood of fire, especially from locomotive sources. Above all else this calls for consistent, regular, and thorough front end inspection and maintenance service. The Mechanical Department of the United States Railroad Administration laid down in Circular No. 5 (Chapter II), very carefully prepared

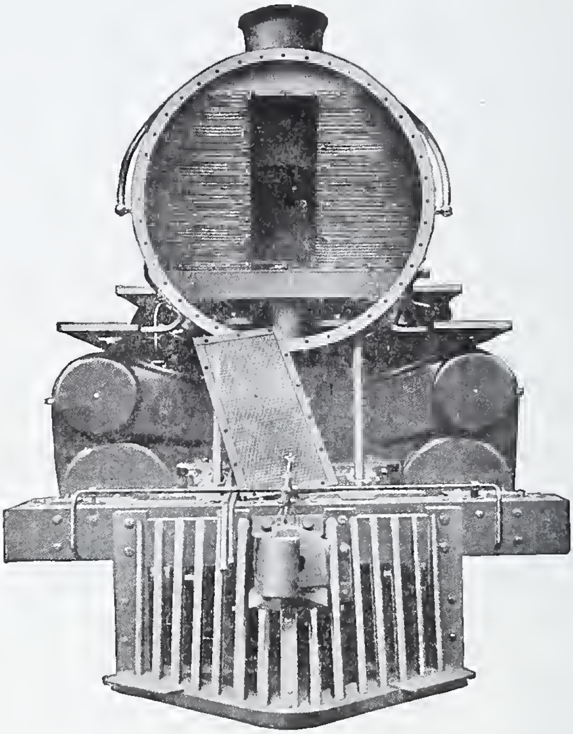

Fig. 19.—Spark arrester netting installation in three pieces.

inspection and maintenance rules. These should be observed and carried out as a minimum rather than a maximum requirement. Special conditions, such as where railroads pass through forest preserves, oil, and gas regions, etc., require extraordinary precautions in this direction. The importance of adequate, conscientious inspection cannot possibly be overestimated.

# CHAPTER V

# LOCOMOTIVE FUELS AND FUEL COMBUSTION

## I. INTRODUCTION

Fuels are special substances whose main element by composition or mixture is carbon. Sometimes they contain additional elements such as hydrogen or sulphur. Usually, however, these are present only in very small quantities. All three of these elements have the power of uniting with oxygen, and hence impart the burning qualities, as it were, to fuel materials.

The characteristics of fuels which are generally considered for purposes of comparison are as follows.

1. Heating value in B.T.U.
    - (a) Total and practically available
2. Proximate analysis
    - (a) Moisture — per cent by weight
    - (b) Volatile matter — per cent by weight
    - (c) Fixed carbon — per cent by weight
    - (d) Ash — per cent by weight
3. Ultimate analysis
    - (a) Carbon — percentage
    - (b) Hydrogen — percentage
    - (c) Oxygen — percentage
    - (d) Nitrogen — percentage
    - (e) Sulphur — percentage
    - (f) Ash — percentage
4. "Residual coal," i.e., coal free from variable factors such as moisture, ash, and sulphur.

These characteristics apply mostly to solid fuels, especially to the different coals. Fuel oils are more simply comparable. There are, to be sure, other important physical and chemical characteristics, but these are more special in nature and will be pointed out when the different fuels are described in detail.

## II. LOCOMOTIVE FUELS

Locomotive fuels may be classified under two general heads—solid and liquid. The solid fuels employed are bituminous coal, semi-bituminous, sub-bituminous, lignite, anthracite, semi-anthracite, coke, and wood. The liquid fuels are petroleum oils. By far the largest portion of locomotive fuel consists of bituminous coal. It is only under very special conditions, predominantly economic, that other types of fuel are used in this service. Occasionally prepared fuels such as briquettes and powdered bituminous coal have been employed, but their use has not become established.

**1. Bituminous Coal.**—Bituminous coal, also commonly known as soft coal, is the most widely distributed throughout the country. It is found especially in the mountain ranges of the Eastern states, such as Pennsylvania, West Virginia, Kentucky; in the Plain states, including Ohio, Indiana, Illinois, Iowa, Kansas, Oklahoma; and in the Rocky Mountain and West Coast states, as Colorado, Utah, Wyoming, New Mexico, Washington and California. Its general distribution, its abundance, and its satisfactory burning and heating qualities are the chief factors which make bituminous coal the most extensively used fuel for locomotive purposes.

The distinguishing characteristics of this coal are primarily its volatile content, its moisture content, its physical texture, and in general its burning qualities. As compared with anthracite coal it is high in volatile matter, contains a fair amount of moisture, and is usually more brittle or friable. When ignited it burns more rapidly, has a long yellow flame, varying somewhat with its hardness, and is apt to give off considerable smoke. Its heat value per pound is approximately the same as that of anthracite. The other coals in comparison are usually richer in moisture, volatiles, and ash, more brittle, and lower in heating value.

Ordinary bituminous coal as far as quality is concerned may be classified into three groups—high grade, medium grade, and low grade. The relative differences are mainly in the heating value, moisture content, and volatile matter present. The better the heat value, the lower as a rule is the moisture and volatile content of a bituminous coal.

Bituminous coals are also distinguished from one another on the basis of their caking or non-caking qualities. By caking coals is meant coals which when slowly heated will cement or fuse together as the volatile matter is driven off. If this heating does not go too far, and if the air supply to the coals is kept down, so that the whole coal mass does not burn intensely, the resulting product is coke. However, when coals of this nature are actively burned the process of their combustion involves their coking temporarily. This is an important characteristic from the spark formation point of view.

Non-caking or free-burning coals do not have the quality of fusing together as they become heated. While apparently coke can be made from them, it is a much more complicated process which does not come into play at all under ordinary firing conditions. Because of the absence of coking in the fire, these latter coals are more satisfactory for steam making purposes. The Eastern coals, especially those very rich in hydrocarbons, have more of a coking nature than the harder Western coals.

**2. Semi-bituminous Coal.**—This coal is harder than ordinary bituminous. Its general burning qualities are better than those of the higher grade bituminous coals, for its moisture as well as its volatile content is lower. For this reason, together with its smokeless and free burning qualities, it is a very desirable fuel for high class power steaming purposes. It is quite well distributed, though in limited quantities, throughout the United States.

**3. Anthracite and Semi-anthracite Coals.**—Anthracite coal is the hardest as well as the heaviest or most dense coal found. It is commonly called hard coal to distinguish it from soft or bituminous coal. Anthracite is mostly all fixed carbon with a limited amount of mineral matter, has very little volatile matter, and a comparatively small amount of moisture. Its heat content is fairly comparable with that of high grade bituminous coal, but not equal to that of semi-bituminous coal. The amount of mineral matter or ash forming materials present tends to lower the heating value of this coal slightly.

Anthracite coal ignites slowly, and because of its density and the absence of volatile matter burns slowly, at a high temperature, with a very short flame, and no smoke. Owing to its firmness it does not give off small particles of carbon which would impart a yellow, smoky nature to the flame. This property also seems to prevent the formation of small spark-forming particles, so that anthracite-burning locomotives are relatively free from spark dangers as long as fair-sized coal is burned. Besides, the draft through an anthracite coal fire must be reduced because of the slower burning qualities of the coal.

Semi-anthracite is not as hard as true anthracite. Its volatile content is somewhat higher. In general this coal is compact in make-up, dull black in color, ignites more easily than hard anthracite, and burns more freely. This coal is found only in limited quantities in a few of the Eastern states.

Both anthracite and semi-anthracite, when used for locomotive purposes, present a special combustion problem due to their slow-burning qualities. They require an enlarged furnace with an increased grate area as compared with the furnace and grate area employed when bituminous coal is used. Owing to this fact, together with the limited amount of anthracite coal available, as well as the strong demand for its use as domestic fuel, anthracite is but little used as a locomotive coal.

**4. Sub-bituminous and Lignite Coals.**—These coals fall in a general division because of their relatively higher moisture and volatile content, as well as their physical qualities when compared with bituminous coals. Ordinary sub-bituminous or black lignite coals, while somewhat similar in most respects to brown lignite coals, differ a good deal in appearance. In the first place, they are black instead of brown; and in the second place, they do not have the structural resemblance to wood which is evident in brown lignite coal. The better grades of sub-bituminous coals are frequently lower in moisture than lignite coals and their heat content may be equal to or even better than that of many bituminous coals.

These coals, however, all have the characteristic of disintegrating upon exposure to the air, and the same is true when they are subjected to the heat of the furnace. They flake or powder up into comparatively small, light particles which ignite freely and really are responsible for the spark troubles encountered with coals of this description.

**5. Fuel Oils.**—Oil is used as locomotive fuel only in those regions traversed by railways where it is reasonably abundant and hence cheap. Or it may be used in some special cases where it is particularly desired to reduce the locomotive spark hazards to zero, for instance in forest preserves.

The types of petroleum found in America do not yield a fuel oil which is quite as desirable for locomotive purposes as, for example, the oils of Russia. Oils which have a low kerosene content and which in consequence yield a high surplus of residuum, lend themselves best to this purpose. With the kerosene removed the fire test of oils is raised so that it becomes comparatively safe as a locomotive fuel. Oils which have a fire test much less than 250°F. are unsafe for this service.

**6. Wood, Coke, Briquettes, and Powdered Coal.**—Wood is used as a locomotive fuel only under special conditions such as are apt to prevail on lumber roads. It was used much more extensively in the past, however. When it is used it requires a special spark preventer arrangement as described in Chapter IV.

Coke is used only in limited instances when it may be mixed with more volatile fuels. It has been employed to help out when firing-up locomotives. It is not a satisfactory fuel for locomotive purposes, because, among other things, it requires a large surplus of air when it is burned.

Briquettes are not used in this country to any large extent, especially as locomotive fuel. Considerable work has been done trying to develop briquettes from waste fuel products, especially anthracite culm and bituminous slack, but efforts have not proved economically successful. In Europe, however, both bituminous coal and peat are briquetted and successfully used.

Powdered coal has been experimented with to a considerable extent in America but it has not to date proved itself a possibility. If it ever does, it will be one effective solution of the locomotive spark problem.

## III. FUEL COMBUSTION

The process of very rapid and active union between the carbon, hydrogen, and other elements of fuel with oxygen in the fire box of the locomotive is known as combustion. This process is essentially a chemical one. Its purpose, as previously pointed out, is to supply heat in large quantities to the boiler so as to convert the water into steam. In order to do this properly in the locomotive, the rate of carrying on this process must be greatly increased over the natural rate at which fuel ordinarily burns, in the open air. This is necessary because the amount of steam which must be generated in the boiler is very large as compared with its size.

The method whereby the rate of combustion in the locomotive furnace is increased, as already explained, consists simply in intensifying the air supply to the fire bed and supplying fuel at high rates. In other words, the draft through the fire is increased. The extent to which the draft is increased or "regulated" is directly proportional to the amount of work performed by the locomotive. As the locomotive is designed and operated, this arrangement works automatically. The heavier the load being pulled, or the faster the train is being moved, the greater the draft, and hence the more intense and rapid the burning of the fire in the fire box.

A good idea of the intensity with which soft coal must burn on the locomotive grate is obtained by comparing locomotive furnace combustion with combustion under other conditions.

Bituminous coal upon a grate in the open air will burn at the rate of 3 pounds per hour per square foot of grate area. Dr. W. F. M. Goss[1] further points out that "in a heating stove, under usual conditions of draft, there will be burned about 5 pounds of coal for each foot of grate, and under a stationary boiler connected with a good stack, the rate may be increased to 10 or even 20 pounds per square foot of grate. Again in naval practice with a closed stack-hole and draft forced by blowers the rate of combustion is occasionally carried as high as 50 pounds per square foot of grate per hour, but this value may be accepted as the maximum rate at which fuel is burned for the purpose of generating steam, except in locomotives." Under ordinary or light service in switching locomotives and the older types of smaller locomotives, the rate of combustion ranges between 50 and 100 pounds per hour per square foot of grate with a maximum of 150 pounds. In the modern high speed or heavy duty locomotive, maximum rates of combustion equalling 200 pounds per hour under special conditions have been reached. With total grate areas equalling 70 square feet, combustion rates of 100 to 150 pounds call for coal handling which equals and frequently exceeds the physical capacity of the fireman. Hence the locomotive stoker has been devised to handle the fuel mechanically from the tender to the fire bed.

The draft necessary to enable the burning of 100 to 200 pounds of coal per square foot of a grate whose area is 70 square feet must obviously be very strong. Taking 150 pounds as an average maximum, the total amount of coal burned per hour would be 10,500 pounds, or a little more than 5 tons. Of course such rates are not usually very long sustained, but they do occur very frequently when the locomotive encounters the ruling grades of a division. In average practice under locomotive conditions each pound of coal requires approximately 200 cubic feet of air for its combustion. This means, then, that when 10,500 pounds of coal are burned per hour, the free air which must be supplied

[1] "Locomotive Sparks," Chapter I, p. 9.

to the fire equals at least 2,100,000 cubic feet. Per minute, this requires at least 500 cubic feet of air to pass through every square foot of the fire, or a total through the entire fire of 35,000 cubic feet. It should not be difficult to see that such a quantity of air as this rushing through the fuel bed, the furnace space, the flues, the front end, and out of the stack, has a strong tendency to carry along the smaller particles of fuel, cinders, or sparks which are present in the fire box.

Thus it is seen that the purely mechanical process of combustion is accompanied by certain strenuous physical phenomena which have a distinct effect on the economy with which the process of combustion is conducted. In addition, these physical phenomena of high draft currents are basically responsible for the spark characteristics of the coal-burning locomotive.

# FIRE LOSSES—
# LOCOMOTIVE SPARKS

## PART II

# PART II

## INTRODUCTION

The importance and general nature of the locomotive spark problem, the conditions which are principally responsible for it, and the principle steps which have been taken by locomotive designers and builders, railroad companies and public authorities to cope with it, have been indicated in Part I. The conclusion cannot be escaped that the problem in its entirety still presents unsolved and controversial phases. Where progress has been made in the solution of some of these phases, it has resulted from scientific observation and experimentation.

Most of the original basic experimental work done on the locomotive spark problem was carried on at Purdue University under the direction of Dr. W. F. M. Goss. He had at his disposal a well-appointed locomotive laboratory and two locomotives. In addition he carried on road tests and made many field observations, the results of which, together with those of his laboratory tests, were summarized and published. Dr. Goss' treatise appeared in 1901. Since then, much additional scientific and experimental work has been done for the purpose of clarifying some of the doubtful aspects of the spark difficulty.

From time to time some of the results of these more recent investigations have been made available in the proceedings of various scientific associations interested in railway subjects. Material in this form, however, is not always easily procurable, nor can results usually be described in ways sufficiently comprehensive and all-inclusive to furnish answers to many of the questions which suggest themselves. Despite the results which have been published, much of the material has had to remain unavailable for general use owing to the specific purpose for which it was originally secured. The necessity for withholding this material now having disappeared, and sufficient new and useful information having been established, the attempt is made in the following pages to collate it properly and present it as a supplementary contribution to the very valuable data already existing.

## CHAPTER VI

## SPARK MATERIAL FORMATION

**1. Cinders and Sparks.**—The spark materials in general which are brought into active being by the strong air currents induced in the locomotive furnace are recognized as of two general kinds, depending upon whether they remain in the front end or are ejected from the stack. These are, respectively, "cinders" and "sparks." Dr. W. F. M. Goss, who has drawn these distinctions[1] defines *cinders* or *front end cinders* as the mixture of finely divided coke and ash which finds its way into the smoke box, remains there, and may later on be removed while the locomotive is at rest. He defines *sparks* as those solid particles coming over from the fire which eventually pass out of the stack by action of the exhaust draft mechanism. Dr. Goss explains that "this term is adopted merely as a definition; it is not strictly descriptive. The cinders which escape from the front end and become sparks retain all the characteristics of front end cinders. Some are composed entirely of ash. Others are of coke which, in their passage of the front end, have been hammered against plates and immersed in steam until they are entirely deprived of fire, and are as incapable of doing damage by fire as the ash itself. All such sparks are commonly referred to as 'dead sparks.'"

### I. CONDITIONS AFFECTING SPARK FORMATION

It is obvious that the main cause of spark and cinder formation in the locomotive is the heavy draft on the fire. But in addition to this there are contributory factors which influence the general process in varying degrees. Thus the manner of firing—hand or stoker—condition of fire, chemical character and physical make-up of the fuel, all have their effect. Coal when fired dry is apt to produce more sparks and cinders than when wetted before firing. Coals which have a caking tendency may not form quite as many sparks as non-caking coals. Some coals are light and friable and, when thrown into the fire, even in large lumps, will break down into smaller fragments as a result of the heat. The harder the coals, the less they are inclined to spark formation. Thus anthracite coal sparks are very light—practically nothing but ash.

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[1] "Locomotive Sparks," W. F. M. Goss, p. 18.

Again, the quantity of sparks formed in a locomotive is affected by its size, or, perhaps better, by the area of the grate and capacity of the boiler. Thus a much greater amount of spark material is formed in a large modern locomotive in heavy duty service than in a small locomotive with limited grate area, in light service.

It does not follow, however, that the large locomotive because of the greater amount of fuel burned per unit is proportionately more of a fire hazard than the small locomotive. The provision of such devices as brick arches, combustion chambers, and extended boiler tubes tend to lengthen the path which sparks must travel before they reach the stack, thus giving them a longer opportunity to burn themselves out. The superheater pipes, header, and damper also introduce additional obstructions to the sparks as they come over from the fire, thus further expediting their breakdown before ejection from the stack. And finally the installation of proper front end netting, supplemented by regular thorough inspection and maintenance, helps to reduce the quantity as well as the fire-carrying capacity of the sparks formed in the larger locomotive.

**2. The Size of the Locomotive.**—From the foregoing remarks, the significance of this element in spark formation is self-evident. A few figures comparing the spark loss of a small locomotive with that of a large modern locomotive are of interest. The small locomotive results were secured at the Purdue University locomotive test plant with Purdue locomotive Schenectady No. 1. A few of the general dimensions of this locomotive are as follows:

| | |
|---|---|
| Wheel arrangement | 4–4–0 |
| Diameter and stroke of cylinders | 17″ × 24″ |
| Diameter of drivers | 63″ |
| Total heating surface | 1,214.48 sq. ft. |
| Grate area | 17.25 sq. ft. |

The large locomotive results were secured at the University of Illinois locomotive test plant with a Baltimore & Ohio Railroad Mikado freight locomotive equipped with superheater and brick arch. The corresponding dimensions of this locomotive were as follows.

| | |
|---|---|
| Wheel arrangement | 2–8–2 |
| Diameter and stroke of cylinders | 26″ × 32″ |
| Diameter of drivers | 64″ |
| Total water and superheating surface | 4,660.0 sq. ft. |
| Grate area | 69.8 sq. ft. |

Broadly speaking, therefore, the heating surfaces and grate areas of the modern Mikado locomotive are about four times those of the Purdue University locomotive.

The fuel used in the Purdue locomotive during the tests in question is described as "Indiana block from the Brazil field, a light fuel which burns freely to a fine ash." The fuel used in the Mikado locomotive was bituminous run-of-mine secured from the Franklin County field of Illinois.

The following table presents the comparative figures in question. The results of two rates of work for each locomotive have been selected—medium and heavy.

Table I.—Effect of Locomotive Size and Grate Area on Spark Formation

| | Draft in inches of water | Total pounds of coal fired per hour | Pounds of coal fired per sq. ft. of grate per hour | Total pounds of cinders and sparks per hour |
|---|---|---|---|---|
| Schenectady No. 1: | | | | |
| Medium rate of work | 1.93 | 791.5 | 45.23 | 34.2 |
| High rate of work | 3.57 | 1,884.4 | 107.68 | 284.7 |
| B. & O. Mikado: | | | | |
| Medium rate of work | 2.9 | 3,201.0 | 45.8 | 99.2 |
| High rate of work | 9.0 | 7,203.0 | 103.2 | 648.3 |

The combustion per square foot of grate surface in the two locomotives for the corresponding rates of work being practically the same, the spark losses per hour of the heavy locomotive are roughly 2½ to 3 times as great as those of the smaller locomotive. Without knowing definitely the physical make-up of the coal used in the small locomotive it is not possible to make an absolute comparison. The figures are sufficiently accurate, however, to show effects of locomotive size on spark formation.

**3. The Effect of the Draft.**—The draft is the most active agent in spark formation. Spark material is produced in proportions varying directly with the strength of the draft. Several recent locomotive tests in laboratories specially equipped with spark-catching devices have furnished excellent data as to how spark formation varies with draft and rate of combustion. Figure 20 shows the relation between the hourly cinder discharge and the hourly coal consumption of a typical saturated steam consolidation freight locomotive built in 1909. Its cylinders were 22″ × 30″, its total heating surface 3283 square feet, and its grate area 49.55 square feet. Figure 21 shows the relation between cinder discharge and the rate of combustion of this same locomotive, while Figure 22 shows the relation of cinder and spark discharge to draft. Bituminous run-of-mine coal from the Mission Field Mine of Vermilion County, Illinois, was used in these tests.

**4. The Make-up of Coal.**—The amount of small material in a locomotive coal, as it is fired, must necessarily affect the quantity of spark and cinder particles which are carried over into the front end and ejected from the stack. While this fact has been generally recognized and indications of its existence have been clearly observed under certain test conditions, it was not until very recently that attempts were made to establish the relationship between spark losses and fine material in the locomotive coal as fired.

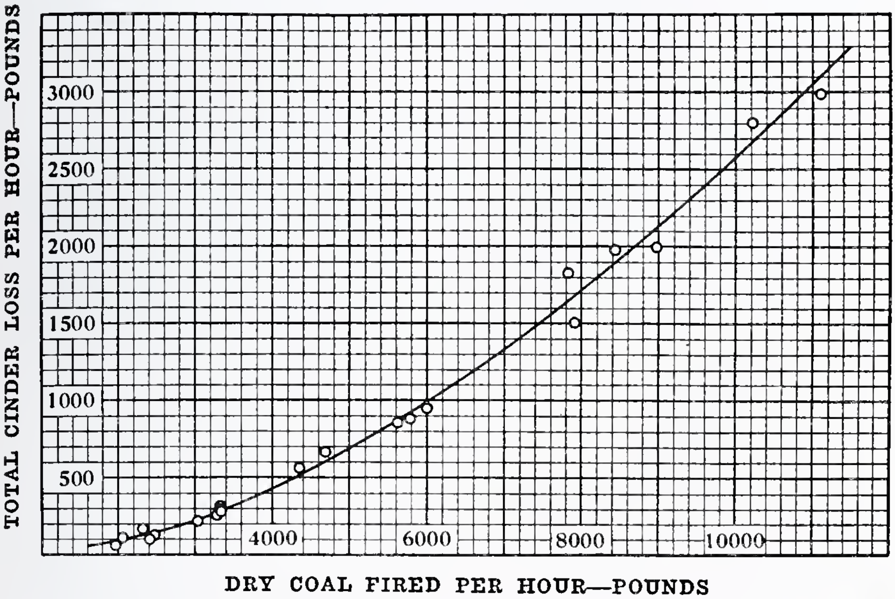

FIG. 20.—The relation between hourly cinder discharge and hourly coal consumption.

During 1916 and 1917 a series of tests in coöperation with the International Railway Fuel Association was run at the locomotive test laboratory of the University of Illinois with six sizes of Illinois coal. The locomotive employed was a modern freight Mikado furnished by the Baltimore & Ohio Railroad Company.

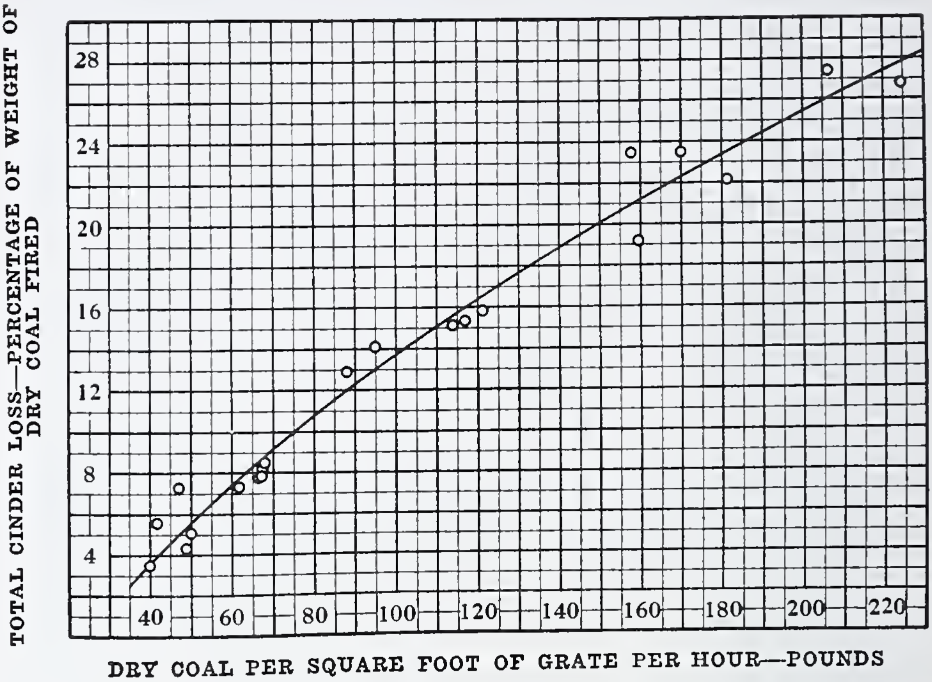

FIG. 21.—The relation between cinder discharge and rate of combustion.

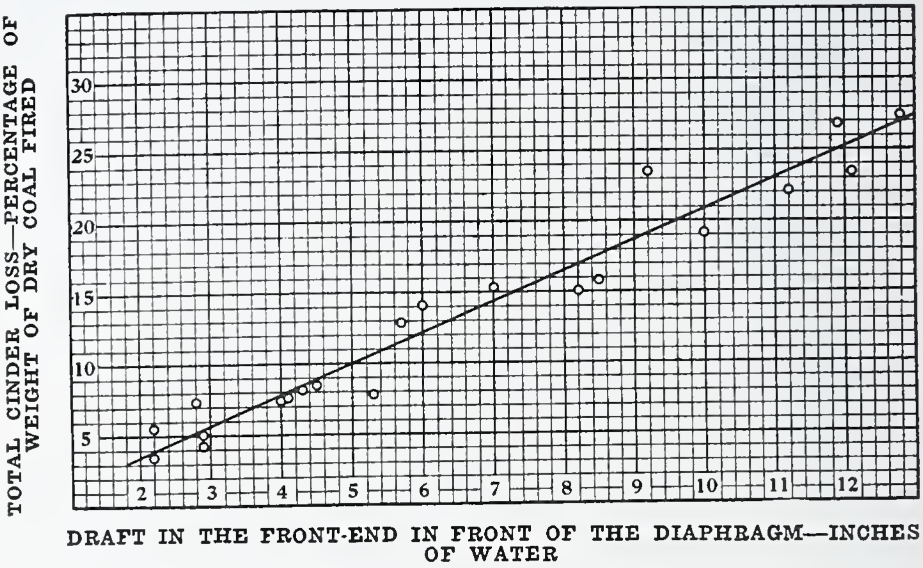

FIG. 22.—The relation between spark discharge and draft.

Its exact type is illustrated in Figure 23. It was built in 1916 by the Baldwin Locomotive Works. It used superheated steam at 190 pounds boiler pressure, in simple cylinders 26″ × 32″.

The front end arrangement of this locomotive was of the general "Master Mechanics" type as adapted to a modern superheater locomotive. The netting used was Draftac. In addition, the furnace was equipped with a Security brick arch. The grates were of box type with openings totaling 17.0 square feet, or 24.4% of the grate area. The stoker with which this locomotive was equipped and which was employed during some of the tests was of the Street type built by the Locomotive Stoker Company.

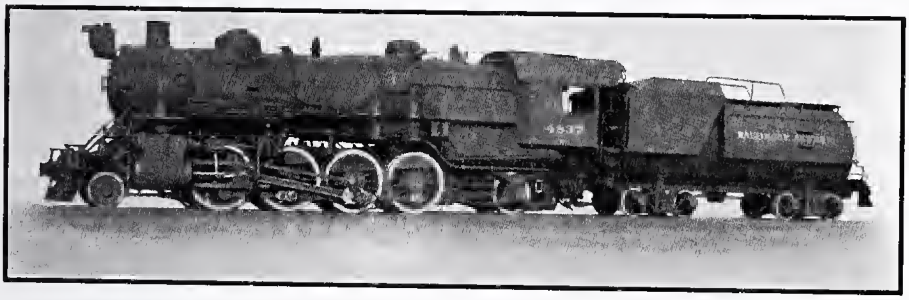

FIG. 23.—Baltimore and Ohio Railroad Locomotive 4837, identical in design with the one used in the University of Illinois coal tests.

Complete reports of the tests and results secured, from which the following data is taken, appear in the Proceedings of the International Railway Fuel Association, 1917, pages 121 to 232, as well as in Bulletin No. 101 of the Engineering Experiment Station, University of Illinois.

The coal used in these tests came from the Franklin County field of Illinois. The sizes or "grades" selected were mine run, 2-inch by 3-inch nut, 3-inch by 6-inch egg, 2-inch lump, 2-inch screenings, and 1¼-inch screenings. Table II shows the chemical analysis and heating values of the coals tested.

The general test program involved for each size of coal six tests, the first three of which were made at a medium rate of evaporation, and the others at a high rate. The medium rate was chosen

TABLE II.—THE CHEMICAL ANALYSES AND HEATING VALUES OF THE COALS, UNIVERSITY OF ILLINOIS TESTS
(The table gives the averages for all tests of each size)

| Size of coal | Proximate analyses, coal as fired | | | | | Calorific values per pound of | | | Ultimate analyses, coal as fired | | | | Moisture in coal determined from sample taken at mine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Volatile matter | Fixed carbon | Ash | Sulphur separately determined | Coal as fired, B.t.u. | Dry coal, B.t.u. | Combustible, B.t.u. | Carbon | Hydrogen | Nitrogen | Oxygen | |
| Mine run............ | 8.14% | 34.18% | 47.92% | 9.76% | 0.95% | 11,873 | 12,926 | 14,463 | 66.63% | 4.28% | 1.55% | 8.69% | 7.82% |
| 2″ × 3″ nut.......... | 8.60 | 34.83 | 47.70 | 8.87 | 0.88 | 11,957 | 13,082 | 14,487 | 67.50 | 4.36 | 1.38 | 8.42 | 8.48 |
| 3″ × 6″ egg.......... | 8.82 | 34.57 | 48.56 | 8.06 | 0.94 | 12,071 | 13,239 | 14,523 | 68.19 | 4.50 | 1.51 | 7.99 | .... |
| 2″ lump............. | 9.27 | 34.46 | 47.49 | 0.07 | 0.88 | 11,817 | 13,023 | 14,469 | 66.34 | 4.23 | 1.49 | 8.73 | .... |
| 2″ screenings......... | 9.25 | 32.05 | 48.12 | 10.59 | 0.85 | 11,550 | 12,727 | 14,408 | 65.74 | 4.43 | 1.48 | 7.66 | .... |
| 1¼″ screenings....... | 9.09 | 32.34 | 47.01 | 10.57 | 0.97 | 11,557 | 12,711 | 14,385 | 65.49 | 4.35 | 1.43 | 8.10 | 9.07 |

to represent an average rate of working the locomotive, in so far as it was possible to define such an average. During the tests run at this medium rate about 23,000 pounds of water were evaporated per hour under the prevailing conditions of steam pressure, superheat temperature and feedwater temperature: from 3100 to 4300 pounds of coal were fired per hour: and the engine was worked at 33% cut-off and at about 19 miles per hour, developing approximately 1300 indicated horse power and about 22,500 pounds drawbar pull. During tests when the engine was worked at the high rate of evaporation, about 43,000 pounds of water were evaporated per hour, the hourly coal consumption varied from about 7000 to 9300 pounds, the cut-off and speed were respectively 55% and 26 miles per hour, while the horse power was about 2200 and the drawbar pull about 28,500 pounds.

The mechanical make-up of the coal as received was determined from properly selected samples for each grade of coal tested by screening them through a specially designed shaker screen, devised by Mr. E. A. Holbrook. The construction of this screen, the method of its operation and the results secured with it are fully described in the publication[1] of the University of Illinois dealing with the tests in question.

Table III shows the percentage by weight of the size elements of the six grades of coal as received at the locomotive laboratory determined by the method indicated above. This table defines therefore the magnitude of the size elements which went to make up each grade of the original coal, thus definitely recording its composition.

A number of illustrations were made which help to clarify the data given in Table III (Figures 24 to 30, inclusive). Each of these applies to one of the sizes, each figure being reproduced from a photograph of the various size elements which came from the screen and which, after weighing, were assembled side by side

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[1] Comparative Tests of Six Sizes of Illinois Coal on a Mikado Locomotive, Bulletin No. 101, Engineering Experiment Station, University of Illinois Bulletin, Sept. 10, 1917, pp. 15–17.

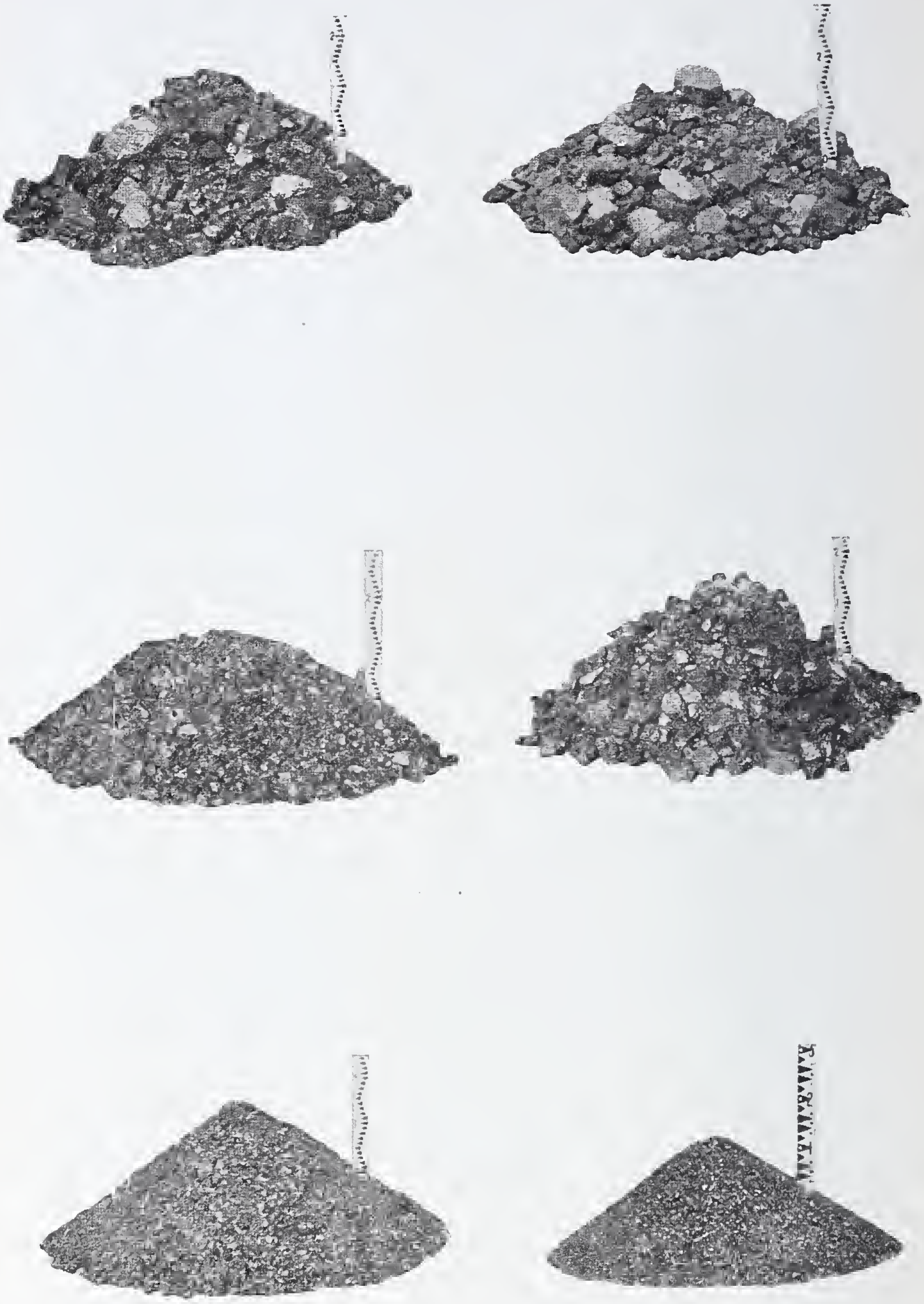

FIG. 24.—The six sizes of coal used during the tests, in the condition in which they were delivered to the laboratory.

FIG. 25.—The size elements of the mine run coal.

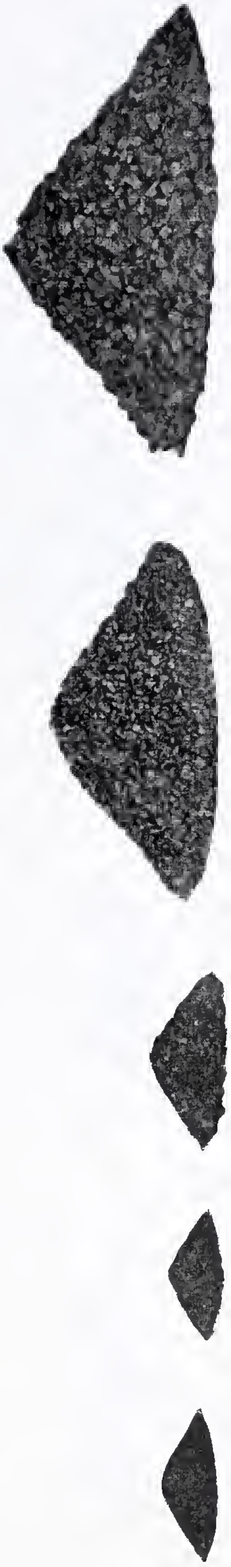

FIG. 26.—The size elements of the 2 inch by 3 inch nut coal.

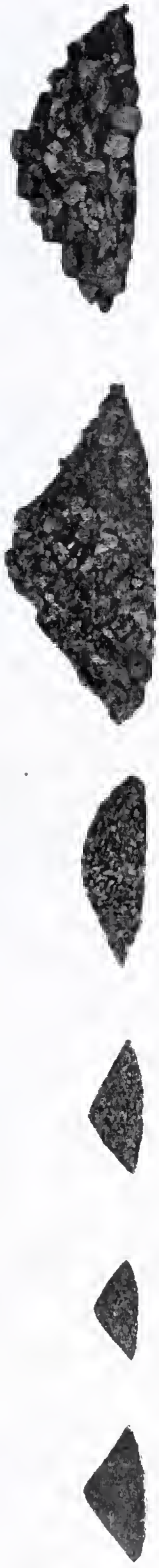

FIG. 27.—The size elements of the 3 inch by 6 inch egg coal.

Fig. 28.—The size elements of the 2 inch lump coal.

Fig. 29.—The size elements of the 2 inch screenings.

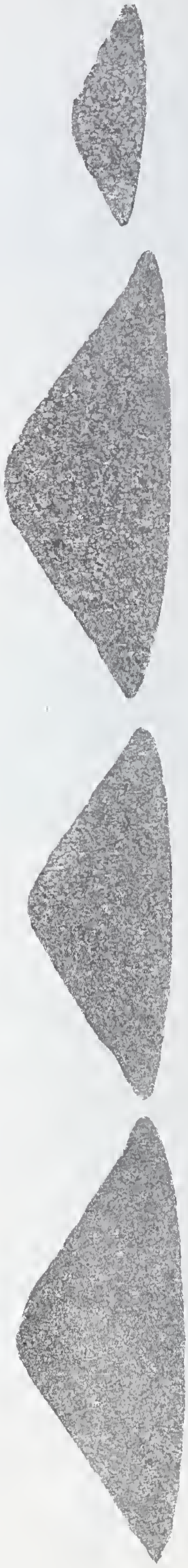

Fig. 30.—The size elements of the $1\frac{1}{4}$ inch screenings.

as shown in the cuts. The information given in the table is thus shown graphically. Photographs were also made of the original coal samples. Figure 24 represents the six sizes of these samples as they were received at the laboratory.

TABLE III.—THE SIZE OF THE COALS AS RECEIVED AT THE LABORATORY, UNIVERSITY OF ILLINOIS TESTS

(This table gives the direct results of the separation made by the use of the laboratory screens)

| Size of coal | Per cent over 4″ screen | Per cent through 4″ over 2″ screen | Per cent through 2″ over 1″ screen | Per cent through 1″ over ½″ screen | Per cent through ½″ over ¼″ screen | Per cent through ¼″ screen | Total in per cent |
|---|---|---|---|---|---|---|---|
| Mine run.......... | 29.6 | 22.3 | 16.8 | 11.4 | 7.4 | 12.5 | 100.0 |
| 2″ × 3″ nut....... | .... | 63.9 | 30.3 | 2.8 | 1.1 | 1.9 | 100.0 |
| 3″ × 6″ egg....... | 41.0 | 48.3 | 5.3 | 2.0 | 1.1 | 2.3 | 100.0 |
| 2″ lump........... | 61.6 | 26.4 | 7.5 | 1.9 | .9 | 1.7 | 100.0 |
| 2″ screenings..... | .... | .... | 33.2 | 25.7 | 14.2 | 26.9 | 100.0 |
| 1¼″ screenings.... | .... | .... | 4.5 | 37.9 | 20.0 | 37.6 | 100.0 |

The facts presented in Table III were recombined to permit tabular and graphical definitions of the grades in a form showing the total portions which passed through each size of screen up to the 4-inch size. The percents so determined were assembled in Table IV and plotted in Figure 31. For the nut coal, curve No. 3 serves to define the composition of the coal and shows not only the percentages, as marked, for the various sized screens through which it actually passed, but also indicates what the percentages would have been for screens of any intermediate size.

TABLE IV

| SIZE OF COAL | Per Cent over 4″ Screen | Per Cent through 4″ Screen | Per Cent through 2″ Screen | Per Cent through 1″ Screen | Per Cent through ½″ Screen | Per Cent through ¼″ Screen |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Mine Run...... | 29.6 | 70.4 | 48.1 | 31.3 | 19 9 | 12.5 |
| 2″ x 3″ Nut.... | .... | .... | 36.1 | 5.8 | 3.0 | 1.9 |
| 3″ x 6″ Egg..... | 41.0 | 59.0 | 10.7 | 5.4 | 3.4 | 2.3 |
| 2″ Lump....... | 61.6 | 38.4 | 12.0 | 4.5 | 2.6 | 1.7 |
| 2″ Screenings ... | . | .... | .... | 66.8 | 41.1 | 26.9 |
| 1¼″ Screenings . | .... | ... | .... | 95.5 | 57 6 | 37.6 |

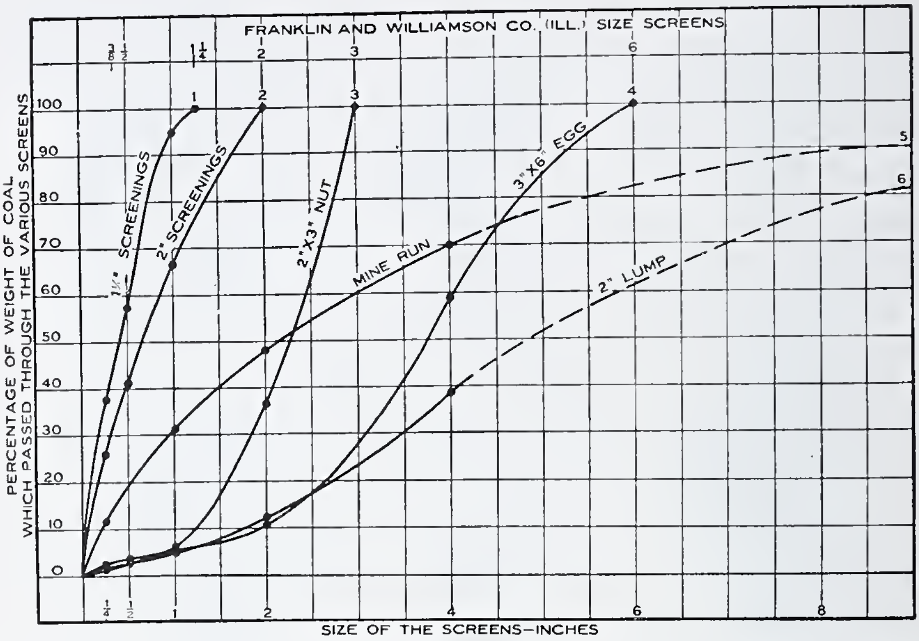

FIG. 31.—The make-up of the coals in the condition in which they were received.

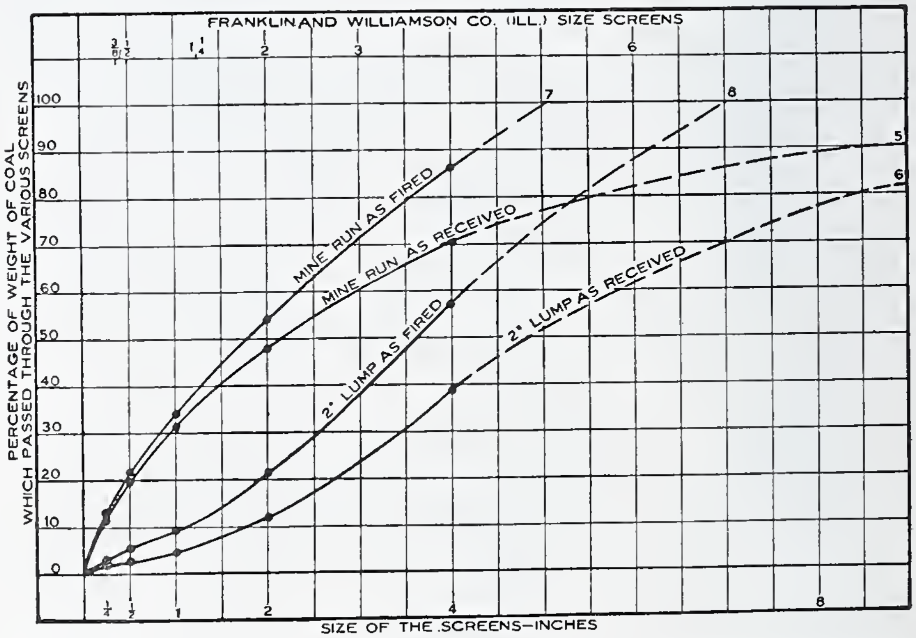

FIG. 32.—The make-up of the mine run and lump coals as received and as fired.

The mechanical make-up of the coal as fired was determined for the mine-run and 2-inch lump grades because these coals underwent additional mechanical break-down just previous to firing. This procedure was necessitated by the fact that these particular coals contained a considerable proportion of lumps too large for proper firing, which therefore had to be broken down with coal picks. The samples thus reduced, of these two grades of coal, were subjected to the same screening process as that previously described. Table V gives the results of the mechanical analysis for these two coals "as fired," and the size percentages of these grades in the condition in which they were received.

TABLE V

**RECEIVED AND AS FIRED**

| SIZE OF COAL | Per Cent over 4" Screen | Per Cent through 4" Screen | Per Cent through 2" Screen | Per Cent through 1" Screen | Per Cent through ½" Screen | Per Cent through ¼" Screen |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Mine Run: | | | | | | |
| As Received.. | 29.6 | 70.4 | 48.1 | 31.3 | 19.9 | 12.5 |
| As Fired..... | 13.1 | 86.9 | 54.3 | 34.3 | 22.0 | 13.8 |
| 2" Lump: | | | | | | |
| As Received.. | 61.6 | 38.4 | 12.0 | 4.5 | 2.6 | 1.7 |
| As Fired...... | 42.7 | 57.3 | 21.0 | 9.0 | 5.3 | 2.0 |

The values in Table V were then plotted (Figure 32). Curve No. 5 applies to mine-run coal as received, and No. 7 to the same grade as fired; while curves Nos. 6 and 8 apply to the 2-inch lump coal in the conditions as received and as fired, respectively. The extent to which these two sizes were broken down is shown by the table and chart. It is apparent from an inspection of the curves that the largest lumps in the mine-run were broken down farther than those in the 2-inch lump coal. After reduction, all mine-run passed through a 5-inch screen, whereas, only about 74% of the lump would pass a screen of this size.

In order to permit comparisons of the mechanical make-up of all six sizes as fired, curves Nos. 1, 2, 3, and 4 from Figure 31 and curves Nos. 7 and 8 from Figure 32 were combined in a single

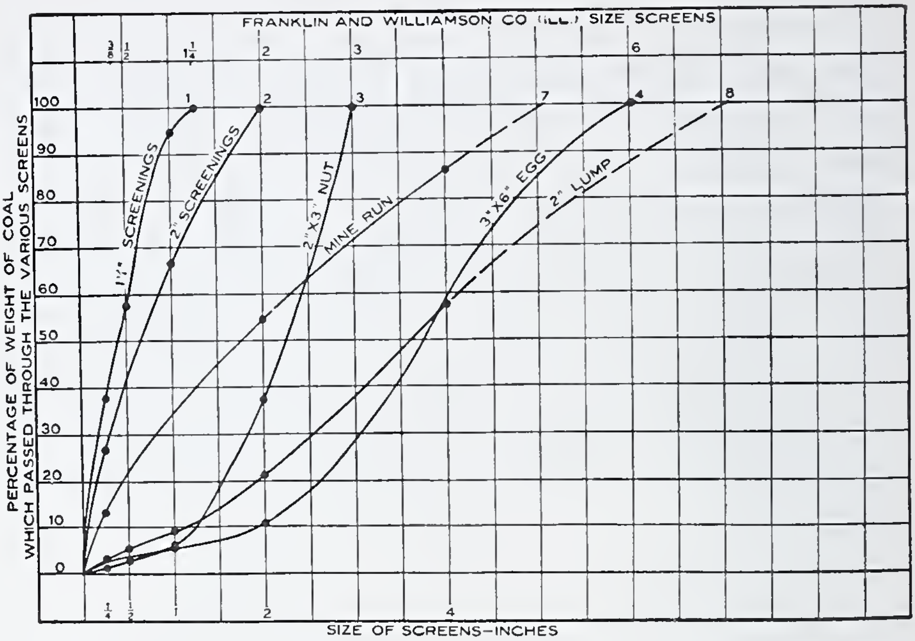

Fig. 33.—The make-up of the coals in the condition in which they were fired.

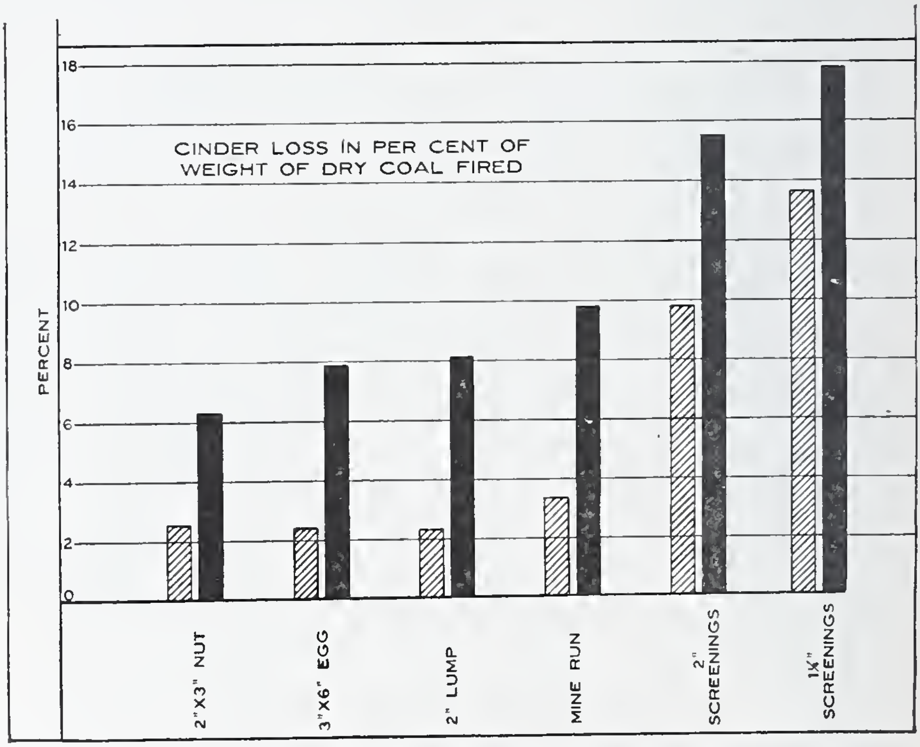

Fig. 34.—The cinder losses expressed as per cent of the weight of the dry coal.

chart (Figure 33) which consequently shows the make-up of all the grades in the condition in which they were fired during the tests.

The conclusions reached in the reports covering the tests in consideration with respect to relation between cinder losses and mechanical make-up of coal as fired are very illuminating. Quoting directly:[1]

> ". . . Information relative to the losses due to cinders[2] passing out through the stack is given in Figure (34) . . .
> and Table VI which show . . .

TABLE VI.—PER CENT OF FINE MATERIAL IN COAL, AND LOSSES DUE TO SPARKS, UNIVERSITY OF ILLINOIS TESTS

| Size | Per cent of fine material in coal as received, passing through | | | Rate | Loss due to sparks | |
|---|---|---|---|---|---|---|
| | ¼″ round hole screen | ½″ round hole screen | 1″ round hole screen | | Wt. of cinders in per cent of | |
| | | | | | Coal as fired | Dry coal |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2″ lump | 1.72 | 2.62 | 4.53 | Medium | 2.1 | 2.3 |
| | | | | High | 7.4 | 8.4 |
| 2″ × 3″ nut | 1.87 | 2.93 | 5.77 | Medium | 2.3 | 2.5 |
| | | | | High | 5.7 | 6.3 |
| 3″ × 6″ egg | 2.28 | 3.40 | 5.40 | Medium | 2.2 | 2.4 |
| | | | | High | 7.2 | 7.9 |
| Mine run | 12.50 | 19.94 | 31.30 | Medium | 3.1 | 3.3 |
| | | | | High | 9.0 | 9.8 |
| 2″ screenings | 26.88 | 41.09 | 66.82 | Medium | 8.9 | 9.8 |
| | | | | High | 14.1 | 15.5 |
| 1¼″ screenings | 37.59 | 57.62 | 95.56 | Medium | 12.5 | 13.6 |
| | | | | High | 16.1 | 17.8 |

> ". . . the amount of stack losses when the weight of the cinders collected from the stack is expressed as a percentage of the weight of the coal fired. . . .
> Thus it is . . .

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[1] Comparative Tests of Six Sizes of Illinois Coal on a Mikado Locomotive, Bulletin No. 101, Engineering Experiment Station, University of Illinois Bulletin, Sept. 10, 1917, pp. 47–52.

[2] The term "cinders" and "stack cinders" is used in these quotations in the same sense in which the term "sparks" or "spark material" is used throughout the rest of this book.

> ". . . seen that, during the medium rate tests, from 2.3 to 13.6 pounds of cinders were collected from the stack for each 100 pounds of dry coal fired; while for the high rate tests from 6.3 to 17.8 pounds were collected for each 100 pounds of coal. The screened coals in all cases produced fewer cinders than the mine-run coal; and the screenings produced a materially greater quantity of cinders than any of the larger ones. . . .
>
> ". . . The figures and data indicate that with very fine coals such as screenings the cinder loss is large even at medium rates of combustion and with comparatively low front-end draft; but that under these conditions the cinder loss is not serious for the larger coals even when they contain a considerable amount of fine material as in mine-run coal. For conditions involving high rates of combustion and strong drafts, however, the stack cinder loss is a serious one for all sizes of coal. . . .
>
> ". . . During tests with the four larger grades, larger quantities of cinders were collected than there was ¼ inch, or smaller, material in the coal. For these coals a considerable portion of the cinders must therefore have come from comparatively large pieces of coal. In the screenings tests the cinders collected were materially less in amount than the ¼ inch or smaller material that existed in the coal. At all comparatively high rates of combustion, therefore, and probably also at lower rates, there must be factors determining the amount of cinders produced other than the original amount of fine material in the coal fired."

The foregoing results, as secured from the University of Illinois tests are of particular value since they give a clue to the relationship between the physical make-up of locomotive coal and the amount of material in the form of sparks which finds its way out of the stack. They are of further value when it is considered that they indicate the existence of factors other than the original amount of fine material in the coal fired which influence the amount of sparks produced. Primarily, however, these results warrant the broad conclusion that ways and means which increase the mechanical handling and thus the fine material in coal such as is done, for instance, by locomotive stokers, make it clearly desirable that the most approved methods for lowering the spark fire hazard be employed.

**5. The Friability of Coal.**—By friability in this instance is meant the tendency of coal to break up into smaller pieces primarily under the influence of heat. Frequently the term is applied to the relative tendency of coal or minerals in general to break up into smaller pieces, due to mechanical action. This meaning, for the purposes of this discussion, will be conveyed by the term *brittleness* rather than *friability.*

There is very little authentic information concerning the relative friability of coals, and apparently still less concerning the causes of this characteristic. Mr. E. A. Holbrook touches upon this quality when he states[1] that the "incipient cleavage determines the lines on which the coal frequently breaks into small blocks on first being heated. This cracking, which is probably due to shrinkage caused by heat expelling the water, is also often more strongly developed in one vertical plane than in the other." Mention has already been made of the rather extreme tendency of sub-bituminous and lignite coals to give off large quantities of sparks, while at the same time these coals, under the influence of the weather, tend rapidly to break up into a loose, almost powdery mass. Apparently the moisture which is contained in coals, notably in those of lower grades, serves as water of composition. When this water is slowly driven off in loosely constructed coals such as sub-bituminous and lignite, they tend to fall apart. When, however, moisture is driven off rapidly under the influence of heat, the adhesion at the cleavage surfaces seems to weaken and the coal, due to both shrinkage and expansion stresses, tends to chip and break down, varying somewhat with the moisture content. The volatile content may also play a part in this phenomenon.

At all events, the spark material found in the locomotive fire box is not entirely due to the fine material in the coal, as is pointed out in the remarks made and test results described under "The

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[1] "Dry Preparation of Bituminous Coal at Illinois Mines," by E. A. Holbrook. Engineering Experiment Station Bulletin No. 88, University of Illinois Bulletin, June 26, 1916, p. 74.

Make-up of the Coal." The last paragraph of the findings reported in Bulletin No. 101 of the Engineering Experiment Station, University of Illinois, is especially pertinent for it indicates clearly that larger quantities of sparks were collected than there was 1¼ inch, or smaller, material in the four larger grades of coals. This can only be accounted for by the apparent tendency of coals to break down to a certain extent while subject to the conditions existing in the locomotive fire box. In this connection it should be noted that this breaking down of the coal and the spark material formation take place soon after the coal is introduced into the fire box, for the spark and cinder material which is collected, shows upon analysis a uniformly high heat value.

**6. The Caking of Coal.**—It is conceivable that the characteristic of some coals to cake or fuse over when introduced into the locomotive furnace might tend to reduce or at least retard the formation of spark material. This caking characteristic, however, detracts from the desirability of such coals for locomotive or steam-making purposes in general. As a rule the ordinary caking coals are comparatively brittle, so that they usually contain much more fine material than the sounder non-caking coals. This factor therefore tends to counteract the fusing quality of the coal in the fire. Consequently it is to be doubted if the caking tendency of coals plays a very large part in the spark material formation when used as locomotive fuels. However, there is very little definite data on this point which would justify any positive conclusions.

**7. The Firing of Coal and Condition of Fire.**—The method of firing locomotive coals and the condition in which the fire is kept on the grates play a part in spark formation. Thus the careful preparation of the coal by breaking down the large lumps has an effect on the amount of fine material fed into the fire box. Uneven or careless firing which permits the formation of holes in the burning fuel bed results in the intensification of the draft through these holes so that additional amounts of small particles are loosened up and carried away. Such conditions also result in the necessity for burning more coal, which in turn increases the total amount of material contributing to spark formation. Again, thick firing versus thin firing affects the situation because of the quantity of coal involved as well as the concentration of draft automatically established through the fire bed. Furthermore, the formation of clinkers on the grates, the raking and hoeing of the fire surface introduce complications which affect the spark question more or less unfavorably. The wetting down of the coal, especially the fine material seems to cause it to stick together better and so perhaps reduces the likelihood of a portion, at least, escaping from the stack. No accurate measurements of the effect of any of these phenomena have ever been made, and it is doubtful if they ever can be made. Their control is subject largely to the skill and experience of the locomotive fireman.

The use of the mechanical stoker for firing locomotive coal also tends to contribute somewhat to spark material formation. This results from the necessity of crushing the coal so that the stoker may handle it properly. The relative amount of fine material is thereby increased. Aside from stoker locomotive tests in which coal screenings were employed as fuel and which under these special circumstances reflected a high spark loss, no data seems to be available showing to what degree the mechanical stoker increases the spark hazard of the locomotive. Determinations along this line, however, can be made with comparative safety by basing them on the results secured in the Illinois tests of six grades of coal described above.

## CHAPTER VII

## THE IGNITION PROPERTIES OF LOCOMOTIVE SPARKS

Having noted the conditions under which locomotive sparks are formed and the factors which affect their formation within the locomotive proper, it is now in order to consider from available data what the distribution and fire-starting properties of locomotive sparks are after they leave the locomotive. Before proceeding with the complicated matter of spark distribution along the railroad right of way, it is well to analyze the fire danger of the individual spark. When the matter of distribution is then considered, there will be a clearer understanding with reference to the likelihood of fires being started by sparks of various sizes after remaining in the air different lengths of time and landing at lesser or greater distances from the railway track.

An investigation of the ignition qualities of locomotive sparks necessarily must concern itself with the determination of the temperature at which sparks strike the ground. For this purpose, as will be more fully described in Chapter VIII, Distribution of Locomotive Sparks, a method has been devised for catching sparks at different distances from the center of the track in pans 12 inches by 12 inches square, lined either with paraffine, cotton fleece, or dry grass. A hot spark landing on the paraffine coating would tend to soften or melt it for a limited area around the place where the spark struck. A hot spark landing on white cotton fleece would discolor, singe, or burn the nap of the fleece and, if hot enough, char or burn a hole into the actual body of the fleece. By carefully heating different sized sparks to specific temperatures, dropping them onto similarly lined pans, and noting the effect by way of softening, melting, or discoloration, it becomes possible to establish a relation between the temperature of these sparks and those caught from locomotives in the field.

Coincident with the determination of a method for estimating the temperature at which locomotive sparks usually strike the ground, it also becomes necessary to establish the temperature at which such sparks actually ignite typical combustible materials if sound judgments are to be formed concerning the liability of fire from such sparks.

## I. LABORATORY DETERMINATION OF SPARK TEMPERATURES AND POWERS OF IGNITION

**1. Preparation of Spark Samples.**—With the end in view, therefore, of securing the data necessary to enable the determination of the temperatures at which sparks strike the ground and at which they ignite typical combustibles, arrangements were made to conduct a series of experiments in the Engineering Laboratories of Purdue University. In preparation for this several hundred pounds of locomotive sparks were collected and carefully sieved into their constituent sizes. The sieves used were ⅝-, ½-, 7/16-, ⅜-, ¼-, and 3/16-inch mesh. The sparks were passed through the sieves in the order named, thus giving the following six sizes:

Over ⅝″
Between ½″ and ⅝″
Between 7/16″ and ½″
Between ⅜″ and 7/16″
Between ¼″ and ⅜″
Between 3/16″ and ¼″

The remaining fine material, i.e., that between 0 and 3/16″, was discarded.

The six classified sizes thus secured represent the maximum as well as the reasonable minimum size of sparks likely to be ejected from a locomotive stack. While sparks of the five larger sizes are probably never thrown out of a locomotive stack except when the spark prevention arrangement is defective, it was considered desirable to investigate these along with the smaller and more normal sizes. It was also expected that indications secured from the exceptionally large sized sparks would reveal the upper limits of the danger of fire from sparks in general as well as the fire risk of locomotives with defective front ends.

After the sparks were separated, as outlined above, test pans 3/8 inch deep and 12 inches square were prepared by pouring paraffine into some of them and lining the others with square white pieces of cotton fleece, nap side up. Special efforts were made to keep the paraffine in all pans of equal depth and the surface smooth and hard.

In addition, very dry excelsior and grass were collected. The excelsior and dry grass samples were each prepared in the form of small, loose bunches. The arrangement of some of these samples is illustrated by Figure 35. The equipment used in these experiments was very simple. Aside from the pans already described, a small chemical furnace heated by a Bunsen burner and equipped with a suitable crucible was used to heat the sparks up to a temperature of 800° F. For the remaining temperatures up to 1800° F. an electric furnace with a Bristol recording pyrometer was employed.

**2. Method of Testing.**—After the furnace had been properly heated a sufficient number of sparks of the desired size were dropped into the crucible, which was then placed in the furnace. The temperature of the furnace was carefully regulated and maintained constant at the desired level for sufficient time, usually three or more minutes, until the sparks were thoroughly heated through.

The pans with paraffine or other materials were placed close by, so that, as soon as the sparks had reached the desired temperature the crucible could be quickly removed and some of the sparks dropped onto the pans or combustibles. This was done with the very least delay possible, thus insuring that the sparks struck the test materials at the temperature at which they left the furnace.

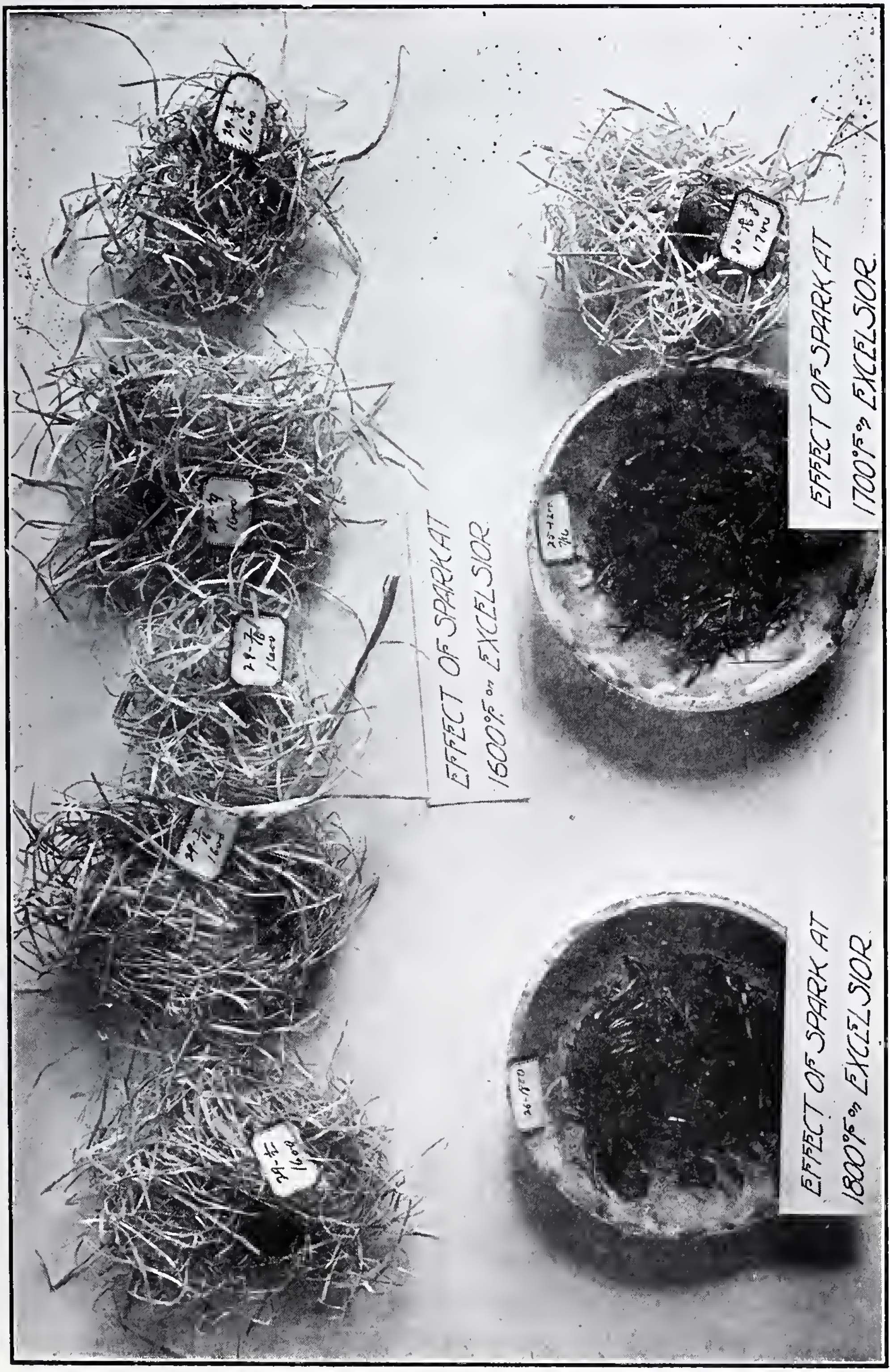
EFFECT OF SPARK AT 1600°F on EXCELSIOR
EFFECT OF SPARK AT 1700°F on EXCELSIOR
EFFECT OF SPARK AT 1800°F on EXCELSIOR

Fig. 35.—Arrangements of excelsior and dry grass samples of combustible used for laboratory determination of spark temperatures and powers of ignition.

The range of temperatures selected was from 100° F. to 1800° F., increasing in 100° increments. As the heated sparks dropped onto the test material surfaces they were very closely observed and the resulting phenomena noted. This procedure was repeated for each spark size for each temperature increment over the complete range. The upper limit, 1800° F., is probably very much greater than that of any spark which may leave a locomotive through its stack.

A written log and a photographic record were made of the effect of the sparks on the various materials tested. Some of the photographic records are shown in subsequent illustrations. They serve exceptionally well to demonstrate the probable effect of sparks of different sizes and at different temperatures on ordinary combustible materials.

3. **Results.**—The results secured by visual observation have been compiled into tabular form and are shown in Table VII. The data is arranged according to size of sparks and increasing temperature increments.

The photographic records taken are also reproduced in Figures 36 to 63. The indications secured by dropping the sparks onto the paraffine pans are shown in Figures 36, 37, 38, 39, 40, 42, 43, 44, 46, 48, 50, 52, 54, 55, 58, 59, 60; and those secured with cotton fleece, excelsior, and grass, respectively, are shown in Figures 41, 45, 47, 49, 51, 53, 56, 57, 61, 62, 63.

4. **Discussion of Results.**—A careful study of both the observations made and the photographs taken, results in some very interesting and useful conclusions with reference to the behavior of locomotive sparks when brought in contact with cold paraffine as well as with the different types of combustibles used.

(a) Sparks at 100° F. to 600° F.—At these temperatures, even the largest sparks failed to show signs of any ability to start fires. From 200° on the sparks all began to stick to the paraffine, which has a melting point between 200° and 300° F. Beyond 300° the paraffine gave indications of melting. At 600° the paraffine began to smoke when the sparks struck it. The sparks also

TABLE VII.—SHOWING RESULTS OF LABORATORY TESTS TO DETERMINE SPARK TEMPERATURES AND IGNITION POWERS

| Test No. | Size of spark | Cotton fleece | Grass | Excelsior | Paraffine | Color of spark |
|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII |
| Temp. | 100° | | | | | |
| 1 | 3/16" | No discoloration | No test made | No test made | One stuck | |
| | 1/4" | No discoloration | No test made | No test made | One stuck | |
| | 3/8" | No discoloration | No test made | No test made | None stuck | |
| 2 | 7/16" | No discoloration | No test made | No test made | None stuck | |
| | 1/2" | No discoloration | No test made | No test made | None stuck | |
| Temp. | 200° | | | | | |
| 3 | 3/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/4" | No discoloration | No test made | No test made | All sparks stuck | |
| | 3/8" | No discoloration | No test made | No test made | All sparks stuck | |
| 4 | 7/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/2" | No discoloration | No test made | No test made | All sparks stuck | |
| Temp. | 300° | | | | | |
| 5 | 3/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/4" | No discoloration | No test made | No test made | All sparks stuck | |
| | 3/8" | No discoloration | No test made | No test made | All sparks stuck | |
| 6 | 7/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/2" | No discoloration | No test made | No test made | All sparks stuck | |
| Temp. | 400° | | | | | |
| 7 | 3/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/4" | No discoloration | No test made | No test made | All sparks stuck | |
| | 3/8" | No discoloration | No test made | No test made | All sparks stuck | |
| 8 | 7/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/2" | No discoloration | No test made | No test made | All sparks stuck | |
| Temp. | 500° | | | | | |
| 9 | 3/16" | No discoloration | No test made | No test made | All sparks stuck | |
| | 1/4" | No discoloration | No test made | No test made | All sparks stuck | |
| | 3/8" | No discoloration | No test made | No test made | All sparks stuck | |
| 10 | 7/16" | Slightly discolored | No test made | No test made | All sparks stuck | |
| | 1/2" | Slightly discolored | No test made | No test made | All sparks stuck | |

TABLE VII (*Continued*)

| Test No. | Size of spark | Cotton fleece | Grass | Excelsior | Paraffine | Color of spark |
|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII |
| Temp. | | | 600° | | | |
| 11 | 3/16″ | No discoloration | No test made | No test made | Paraffine smoked | ........... |
| | 1/4″ | No discoloration | No test made | No test made | Paraffine smoked | ........... |
| | 3/8″ | Slight discoloration | No test made | No test made | Paraffine smoked | ........... |
| 12 | 7/16″ | Perceptibly scorched | No test made | No test made | Cinder imbedded | ........... |
| | 1/2″ | Perceptibly scorched | No test made | No test made | Cinder imbedded | ........... |
| Temp. | | | 700° | | | |
| 13 | 3/16″ | No discoloration | No test made | No discoloration | All sparks stuck | ........... |
| | 1/4″ | No discoloration | No test made | No discoloration | All sparks stuck | ........... |
| | 3/8″ | Dark brown | No test made | No discoloration | Smoked gave odor | ........... |
| 14 | 7/16″ | Scorched light brown | No test made | Charred | Smoked | ........... |
| | 1/2″ | Scorched light brown | No test made | Charred | Smoked | ........... |
| Temp. | | | 800° | | | |
| 15 | 3/16″ | .......... | No test made | ........... | ........... | ........... |
| | 1/4″ | Small discoloration | No test made | ........... | ........... | ........... |
| | 3/8″ | Discolored dark brown | No test made | Very slight colored | Smoked | ........... |
| 16 | 7/16″ | Discolored dark brown | No test made | Very slight colored | Smoked | ........... |
| | 1/2″ | Discolored dark brown | No test made | Very slight colored | Smoked | ........... |
| Temp. | | | 900° | | | |
| 17 | 3/16″ | No discoloration | No test made | No discoloration | Smoked | ........... |
| | 1/4″ | Scorched brown | No test made | Charred | Smoked | ........... |
| | 3/8″ | Scorched brown | No test made | Charred | Smoked | ........... |
| | 7/16″ | Scorched brown | No test made | Charred | Smoked | ........... |
| | 1/2″ | Scorched dark brown | No test made | Charred | Smoked | ........... |
| Temp. | | | 1000° | | | |
| 18 | 3/16″ | Very slightly discolored | No test made | Browned | ........... | ........... |
| | 1/4″ | Discolored dark brown | No test made | Slightly discolored | ........... | ........... |
| | 3/8″ | Slightly charred | No test made | Slightly discolored | ........... | ........... |
| | 7/16″ | Charred | No test made | Charred | .......... | Gave off gases |
| | 1/2″ | Charred dark brown | No test made | Charred | ........... | ........... |
| | 5/8″ | Charred | No test made | Charred | .......... | Gave off gases |

TABLE VII (*Continued*)

| Test No. | Size of spark | Cotton fleece | Grass | Excelsior | Paraffine | Color of spark |
|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII |
| Temp. | 1100° | | | | | |
| 19 | 3/16" | Slightly discolored | No test made | Slightly discolored | .......... | .......... |
| | 1/4" | Slightly discolored | No test made | Charred | .......... | .......... |
| | 3/8" | Charred dark brown | No test made | Charred | .......... | .......... |
| | 7/16" | Charred | No test made | Smoked | Smoked badly | .......... |
| | 1/2" | Charred | No test made | Charred | .......... | Faint red |
| | 5/8" | Charred | No test made | Charred smoked | .......... | .......... |
| Temp. | 1200° | | | | | |
| 20 | 3/16" | Discolored dark brown | No test made | Slightly charred | .......... | .......... |
| | 1/4" | Charred | No test made | Slightly charred | Simmered | Faint red |
| | 3/8" | Charred smoked | No test made | Smoked | Simmered | Dull red |
| | 7/16" | Charred smoked | No test made | Charred smoked | Simmered | Dull red |
| | 1/2" | Charred | No test made | Charred | .......... | Dull red |
| | 5/8" | Charred | No test made | Charred | .......... | Gave off gases |
| Temp. | 1300° | | | | | |
| 21 | 3/16" | Charred dark brown | No test made | Charred | .......... | Dull red |
| | 1/4" | Slight blaze | No test made | Charred | .......... | Glowing red |
| | 3/8" | Slight blaze hole through | No test made | Smoked | .......... | Glowing red |
| | 7/16" | Charred | No test made | Charred | .......... | Glowing red |
| | 1/2" | Slight blaze hole through | No test made | Separate pieces burnt | .......... | Glowing red |
| | 5/8" | .......... | No test made | Separate pieces burnt | .......... | Dull red |
| Temp. | 1400° | | | | | |
| 27 | 3/16" | Slowly burned | Slightly colored | Discolored | .......... | Glowing red |
| | 1/4" | Slowly burned | Slightly scorched | Sparked | .......... | Glowing red |
| | 3/8" | Slowly burned | Slightly charred | Sparked | .......... | Glowing red |
| | 7/16" | Slowly burned | Slightly charred | Slight scorch | .......... | Glowing red |
| | 1/2" | Slowly burned | Charred smoked | Smoked | .......... | Dark red |
| | 5/8" | No test made | No test made | No test made | .......... | .......... |

TABLE VII (*Concluded*)

| Test No. | Size of spark | Cotton fleece | Grass | Excelsior | Paraffine | Color of spark |
|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII |
| Temp. | 1500° | | | | | |
| 28 | 3/16" | Slowly burned | Slightly scorched | Slightly scorched | .......... | Bright red |
| | 1/4" | Charred | Smoked charred | Slightly charred | .......... | Bright red |
| | 3/8" | Slowly burned | Smoked charred | Sparked | .......... | Bright red |
| | 7/16" | Charred | Smoked charred | Sparked | .......... | Bright red |
| | 1/2" | Slowly burned | Badly charred | Sparked | .......... | Bright red |
| No test made | + | + | + | + | + | + |
| Temp. | 1600° | | | | | |
| 29 | 3/16" | Slowly burned | Slightly charred | Sparked | .......... | Bright red |
| | 1/4" | Slightly scorched | Slightly charred | Charred | .......... | Bright red |
| | 3/8" | Charred | Slightly charred | Sparked | .......... | Bright red |
| | 7/16" | Flashed slowly burnt | Charred smoked | Sparked | .......... | Bright red |
| | 1/2" | Charred | Slight burning | Slowly burned | .......... | Bright red |
| Temp. | 1700° | | | | | |
| 30 (See note) | 3/16" | Slightly scorched | Charred | Slightly charred | .......... | Intense glow |
| | 1/4" | Flashed and burned | Smoked charred | Specimen burned | .......... | Intense glow |
| | 3/8" | Flashed and burned | Smoked charred | Charred | .......... | Intense glow |
| | 7/16" | Flashed and burned | Sparked flashed | Specimen burned | .......... | Intense glow |
| | 1/2" | Flashed and burned | Burned over small area | Specimen burned | .......... | Intense glow |
| Temp. | 1800° | | | | | |
| 26 | 3/16" | Slightly scorched | Slightly scorched | Slight sparked | .......... | Very bright glow |
| | 1/4" | Charred | Scorched smoked | Smoked | .......... | Very bright glow |
| | 3/8" | Flashed blazed | Blazed | Charred | .......... | Very bright glow |
| | 7/16" | Burned | Blazed | Blazed and burned | .......... | Very bright glow |
| | 1/2" | Burned | Blazed | Blazed burned | Blazed | Very bright glow |

NOTE.—Cotton results from test No. 25.

imbedded themselves slightly, due to local melting. This was especially true of the larger sparks, i.e., those beyond ⅜ inch in size. Figures 36 to 40 show sparks dropped onto paraffine. It will be noted that there are no perceptible disturbances to the paraffine except perhaps in the case of four of the larger 600° sparks.

The effect of the sparks at these temperatures on cotton fleece did not become apparent until 500° were reached. Then only the larger ones, ⅜ inch and above, began to set up slight discolorations upon the fleece where they rested. At 600° these discolorations became decidedly marked, for the 7/16 inch and ½ inch sizes practically scorching the fleece. Figure 41 shows the effect these larger sparks have on cotton fleece. This effect, from a fire starting point of view, is not pronounced. Sparks which strike the ground at temperatures such that they will barely stick to paraffine or discolor cotton fleece are not dangerous.

(b) Sparks at 700° F.—The tabulated results for sparks at this temperature indicate that the smaller sizes tend to stick to the paraffine, whereas the larger sizes caused slight local melting and some smoking. In the case of the cotton fleece the 3/16 inch and ¼ inch sparks failed to do any discoloring. The larger sizes, however, did scorch and discolor the fleece to a slightly heavier extent than the sparks heated to 600°. It was also found that the larger sparks charred excelsior. The effect of various sizes of sparks heated to 700° is shown in Figure 42 for paraffine and Figure 41 for cotton fleece. At this temperature the sparks are not hot enough to start fires.

(c) Sparks at 800° F.—At this temperature the paraffine began to show signs of marked local melting. The smaller sparks were thoroughly imbedded and a distinct area of disturbance appeared around them, caused largely by radiated heat. The largest sparks melted their way through the paraffine layer and lodged on the metal bottom of the pan. These effects are illustrated in Figure 43.

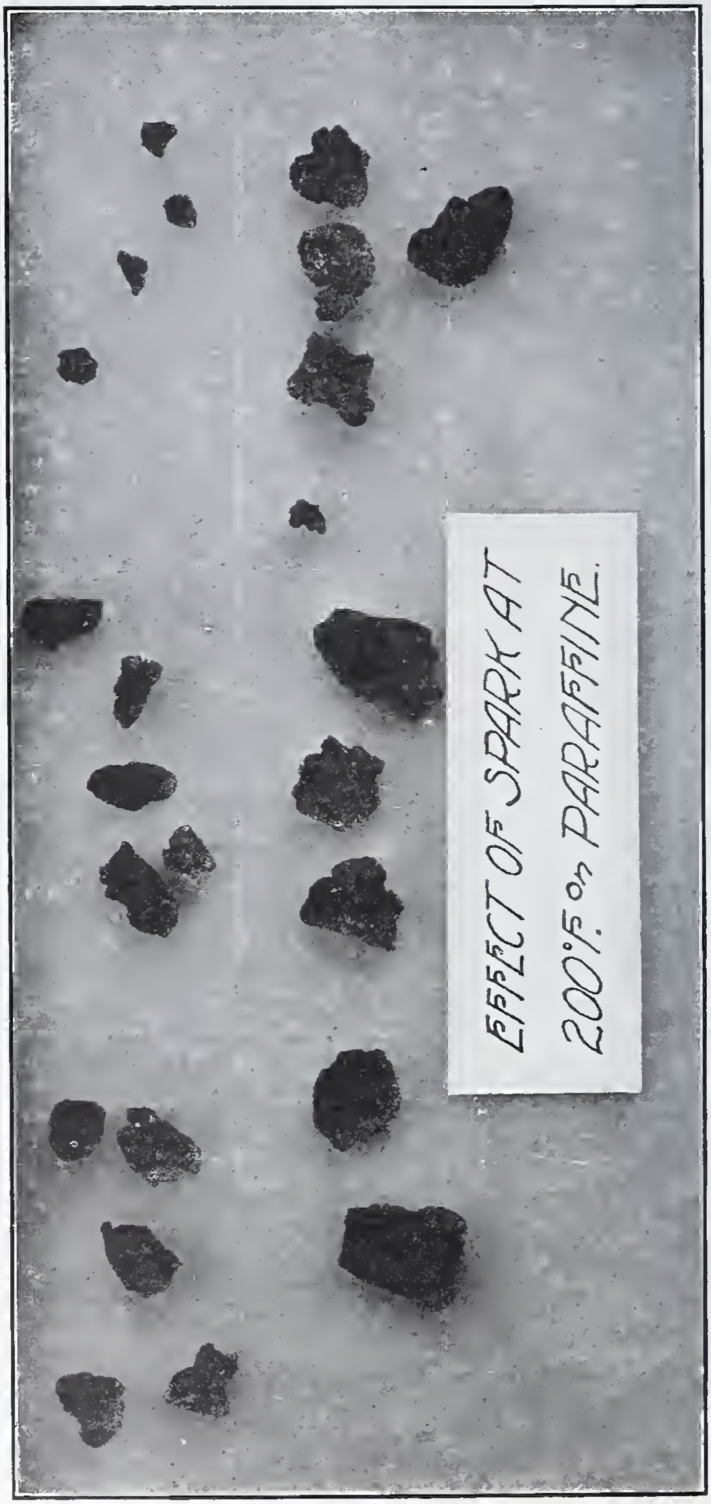

Fig. 36.—Effect of different size sparks at 200° F. on paraffine.

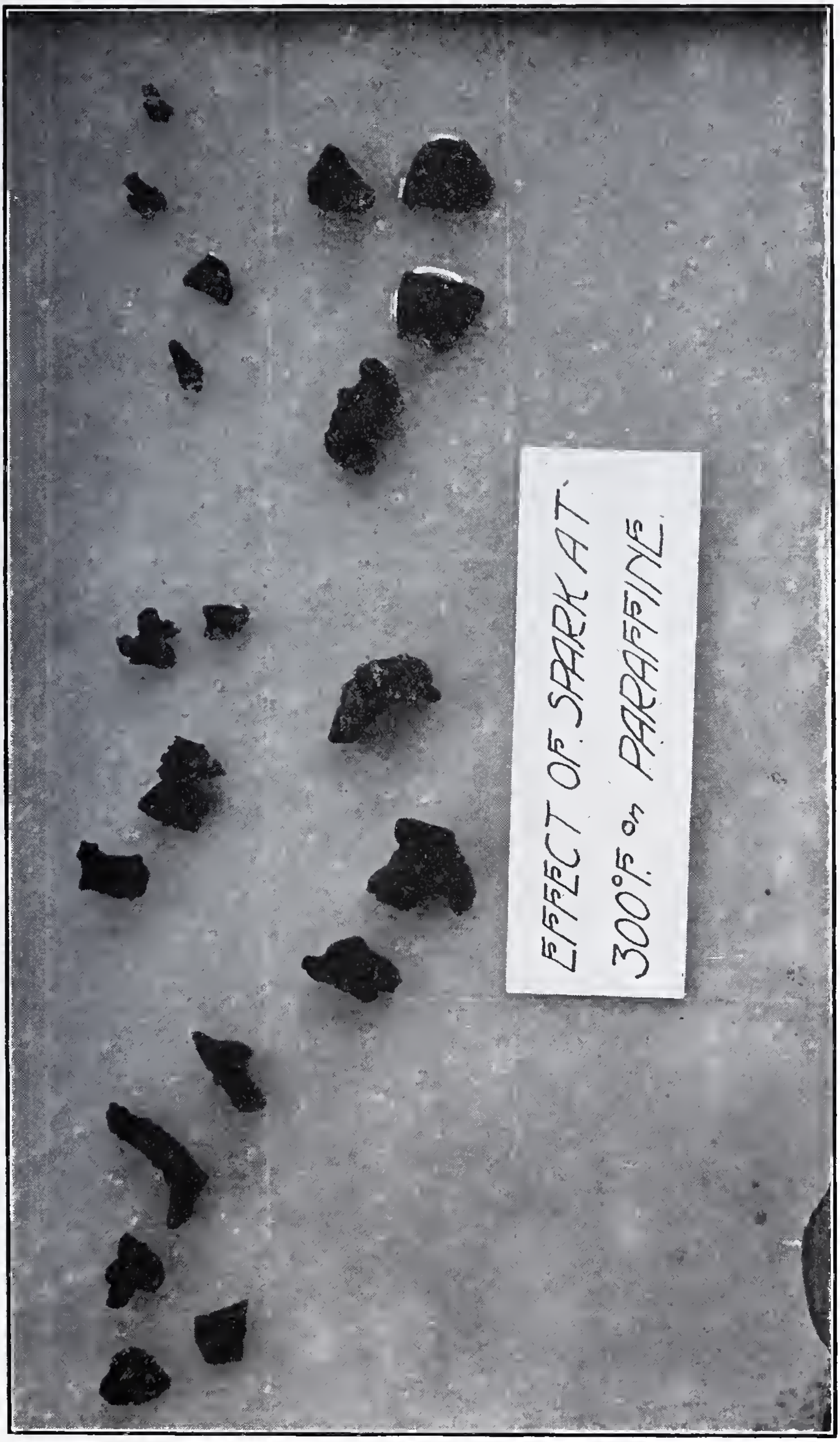

FIG. 37.—Effect of different size sparks at 300° F. on paraffine.

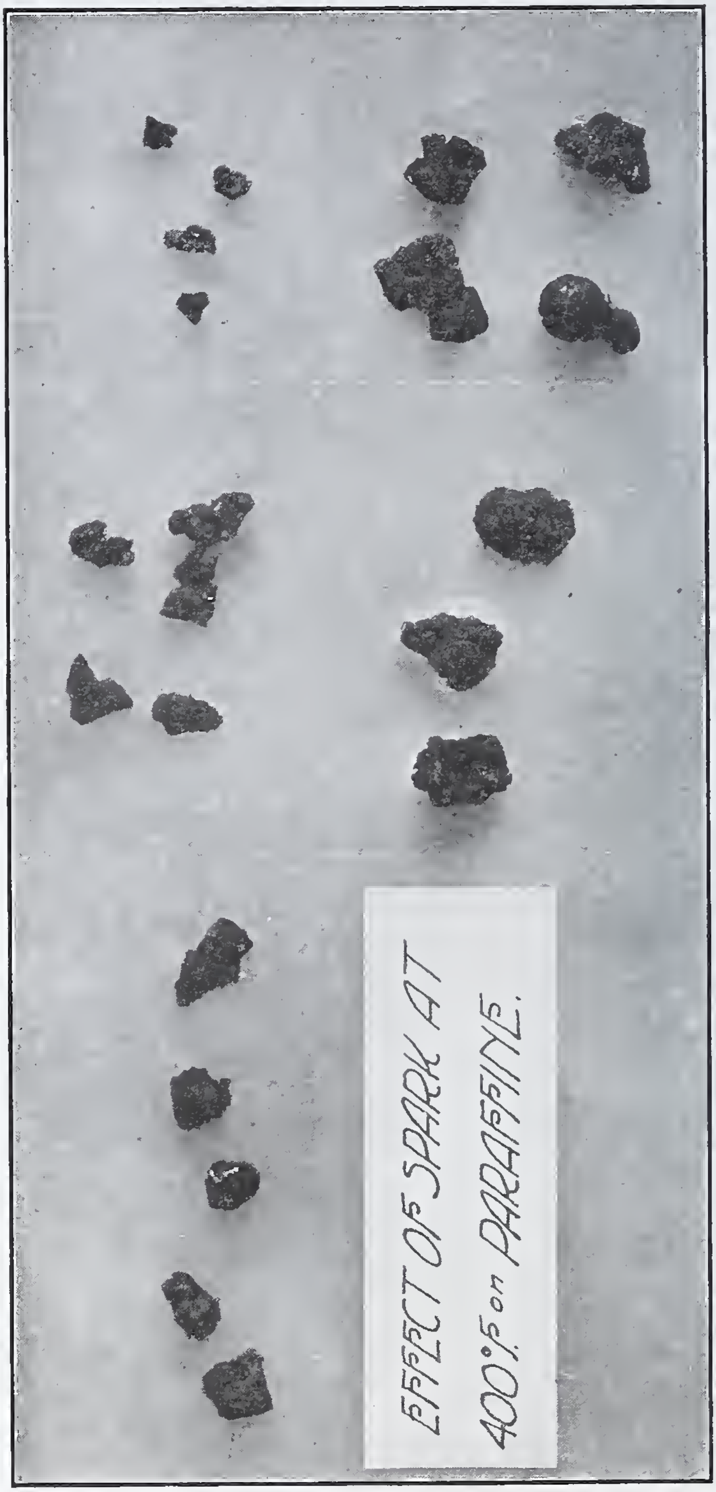

Fig. 38.—Effect of different size sparks at 400° F. on paraffine.

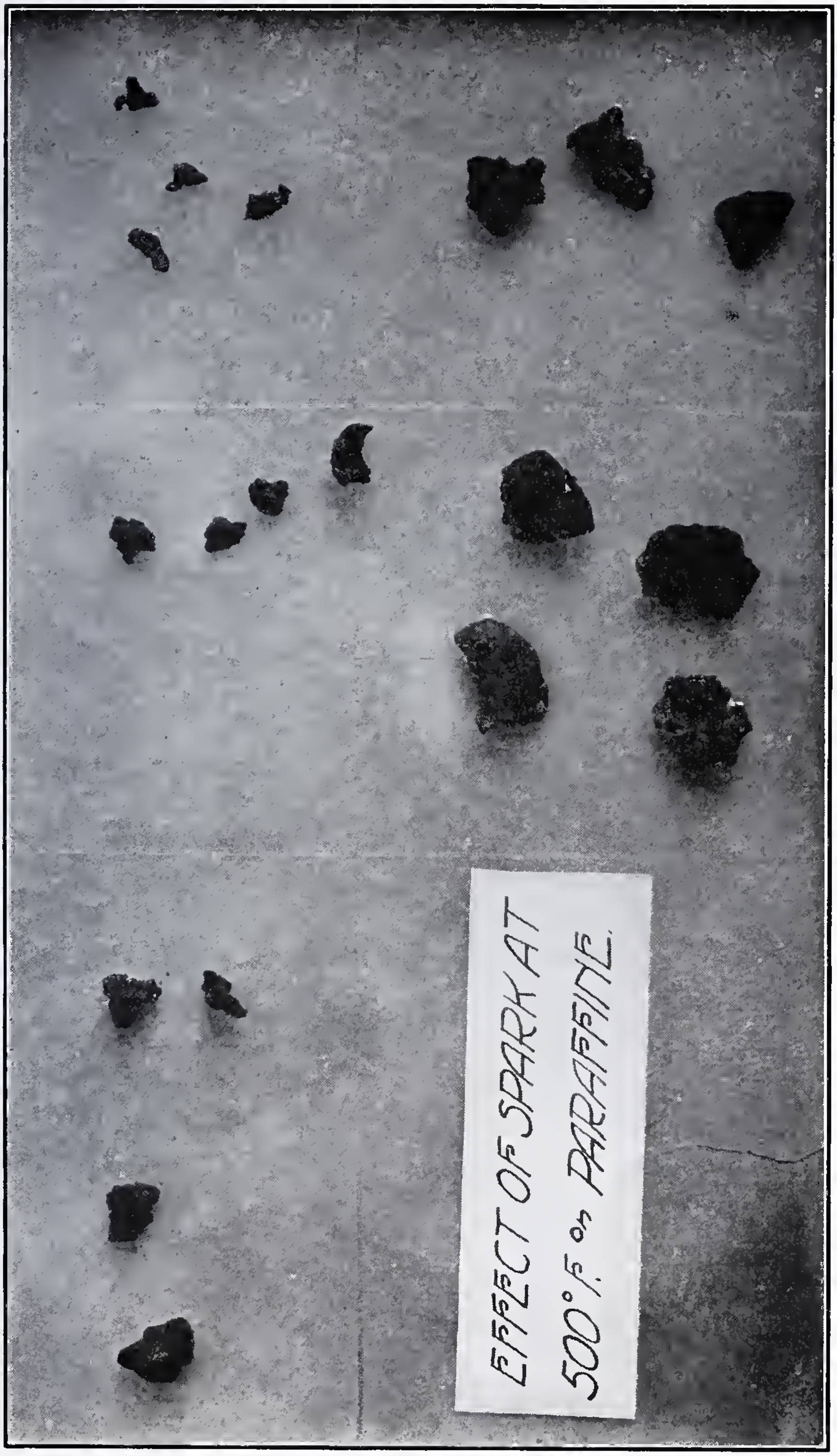

Fig. 39.—Effect of different size sparks at 500° F. on paraffine.

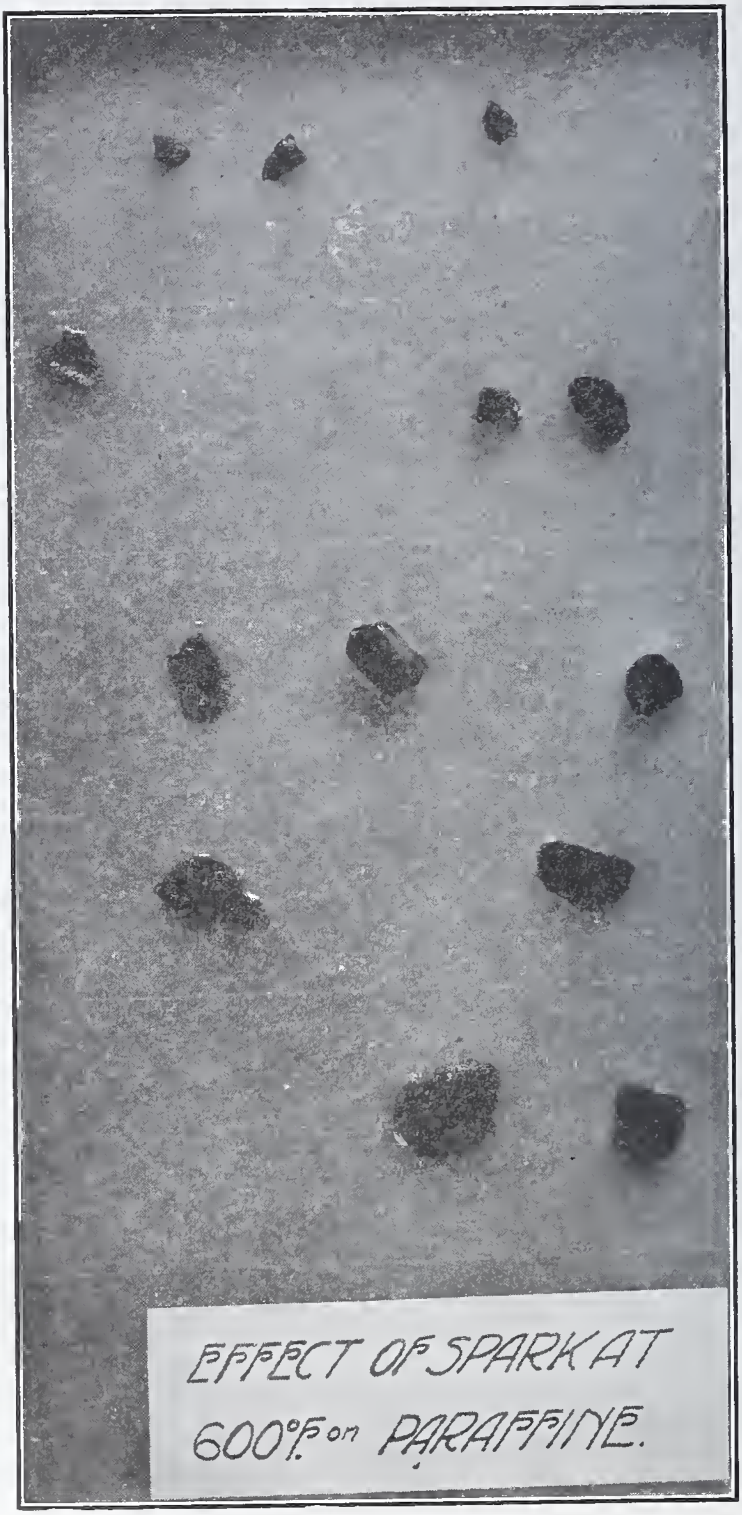

FIG. 40.—Effect of different size sparks at 600° F. on paraffine.

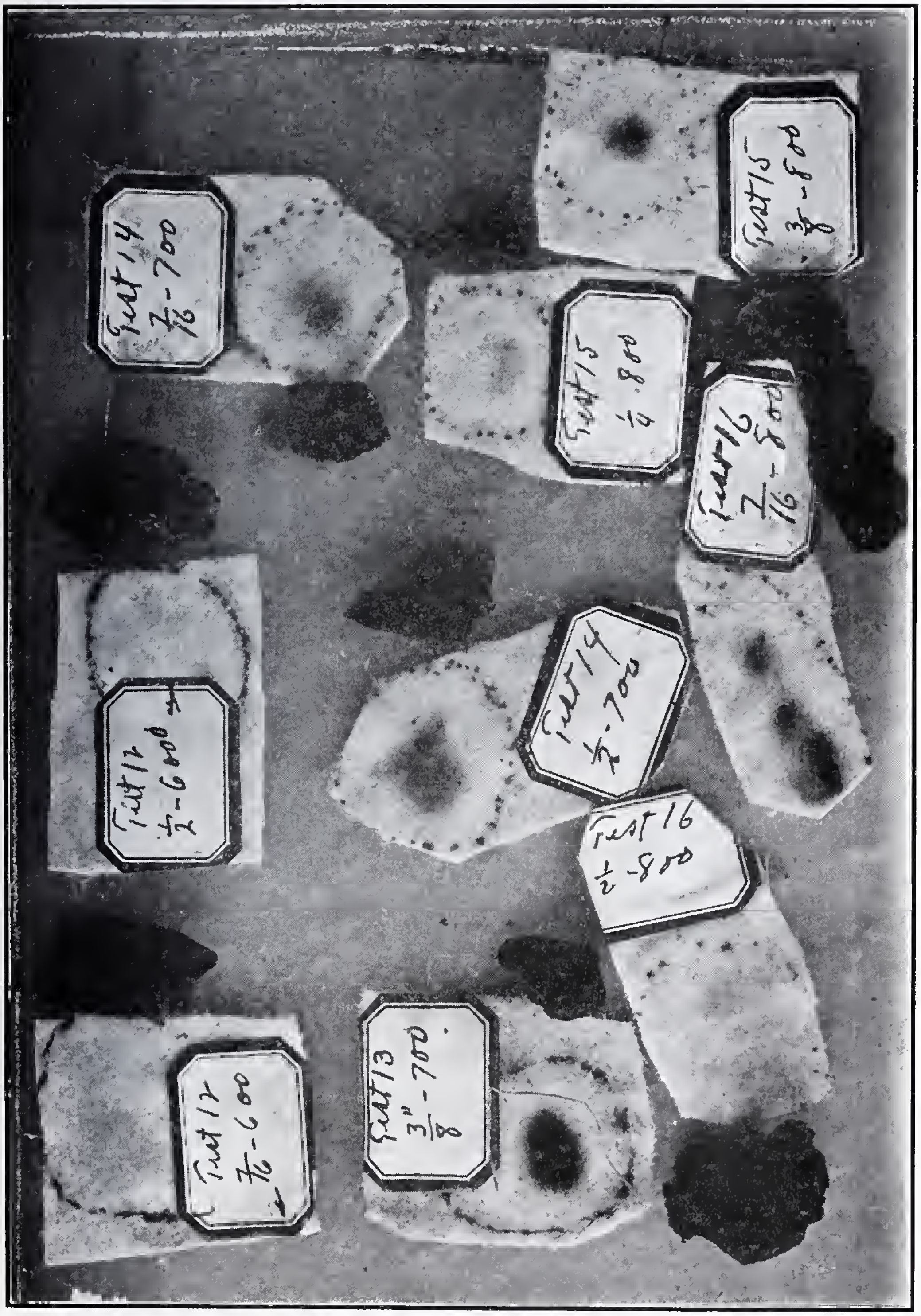

FIG. 41.—Effect of different size sparks at 600°, 700°, 800° F. on cotton fleece.

The discoloration of the fleece was a little more pronounced than at the previous temperature of 700°. No signs of burning or charring, however, developed. The excelsior tests showed slight coloring, no indications of a tendency to start burning. Figure 41 gives an idea of the effect of the larger sparks on fleece.

(d) Sparks at 900° F.—There was no very marked difference in the effects of sparks at this temperature on the paraffine plates as compared with sparks at 800°. The cotton fleece, however, showed signs of more pronounced marking, the scorching appearing as dark brown rather than light brown. The excelsior samples were definitely charred. Figure 44 shows the paraffine pan test results and Figure 45 the cotton fleece test results.

(e) Sparks at 1000° F.—All of these sparks, except the two smaller sizes melted the paraffine so that they lodged on the bottom of the pan, as shown by Figure 46. The cotton fleece was very perceptibly affected. However, only the larger sparks, 7⁄16 inch, ½ inch, ⅝ inch, did serious damage by charring the fabric at the point of contact so that it no longer had coherence. Nevertheless the material did not start to burn. Figure 47 illustrates this result. This is significant as sparks of such size could never pass the netting commonly used when in good repair—and even if in such condition as to permit such sparks passing, the probability of fire would be remote because at 1000° cotton fleece did not flash. Furthermore it is unlikely that sparks ever reach the ground at a temperature of 1000°. The excelsior only showed signs of charring. The sparks at this temperature also gave evidence of releasing traceable gases.

(f) Sparks at 1100° F.—At this temperature the melting of the paraffine became extended in area, especially for the smaller sparks, when compared with the next preceding paraffine test results. The fleece and excelsior also showed more decided discoloring and charring effects. In fact, the excelsior began to give off smoke. The sparks, when observed, showed a faint glowing. Figures 48 and 49 record the paraffine and fleece results, respectively.

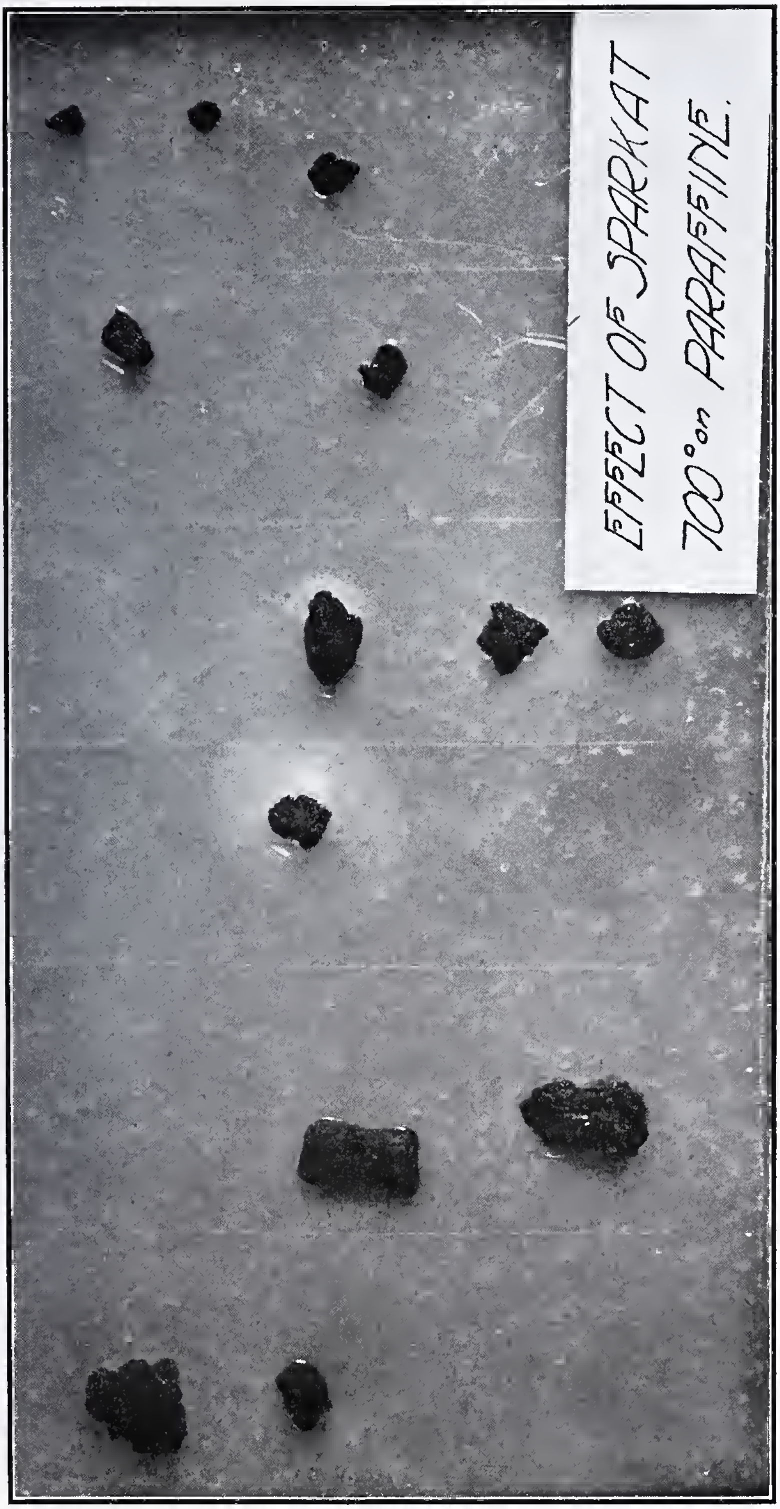

FIG. 42.—Effect of different size sparks at 700° F. on paraffine.

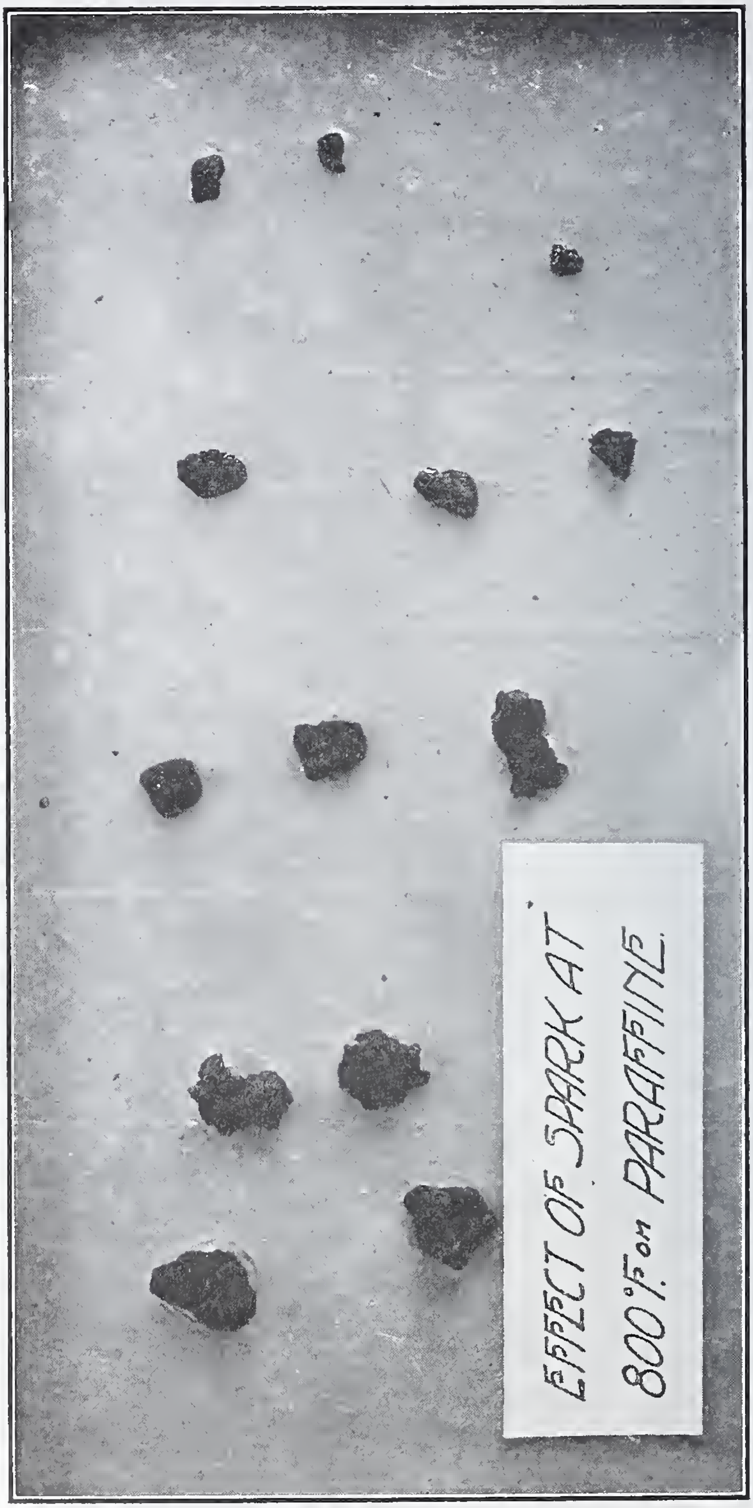

FIG. 43.—Effect of different size sparks at 800° F. on paraffine.

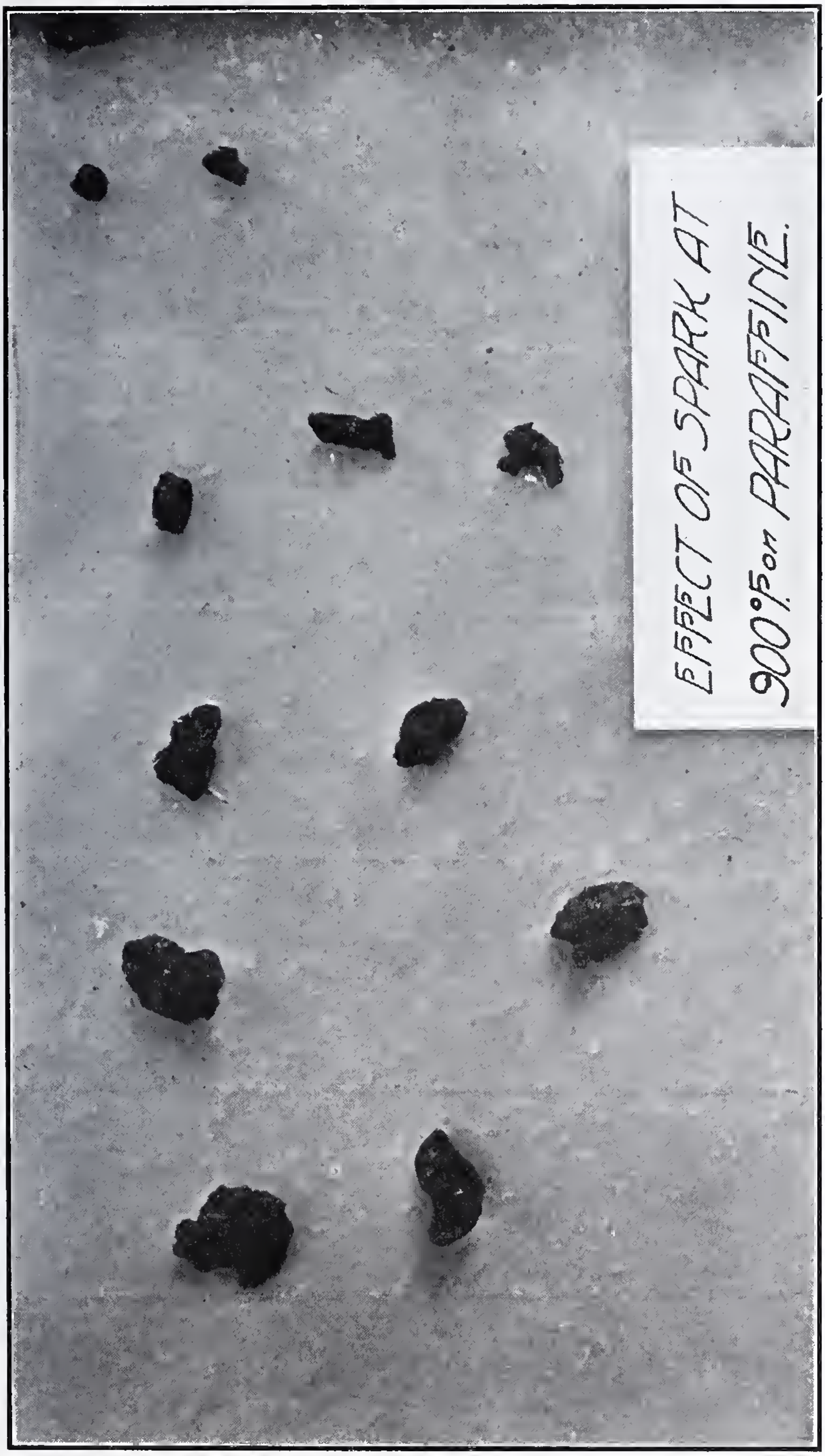

Fig. 44.—Effect of different size sparks at 900° F. on paraffine.

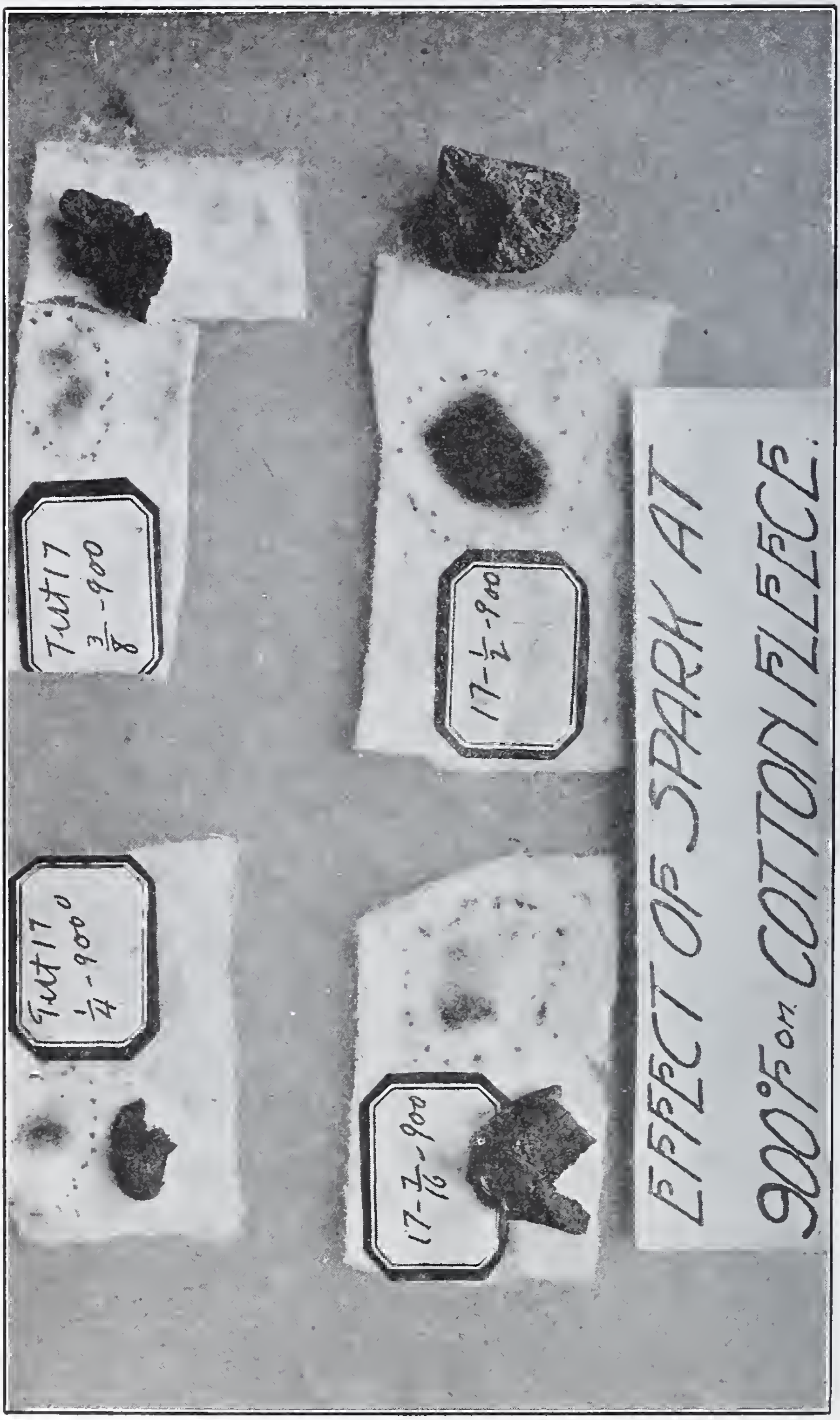

Fig. 45.—Effect of sparks of different size sparks at 900° F. on cotton fleece.

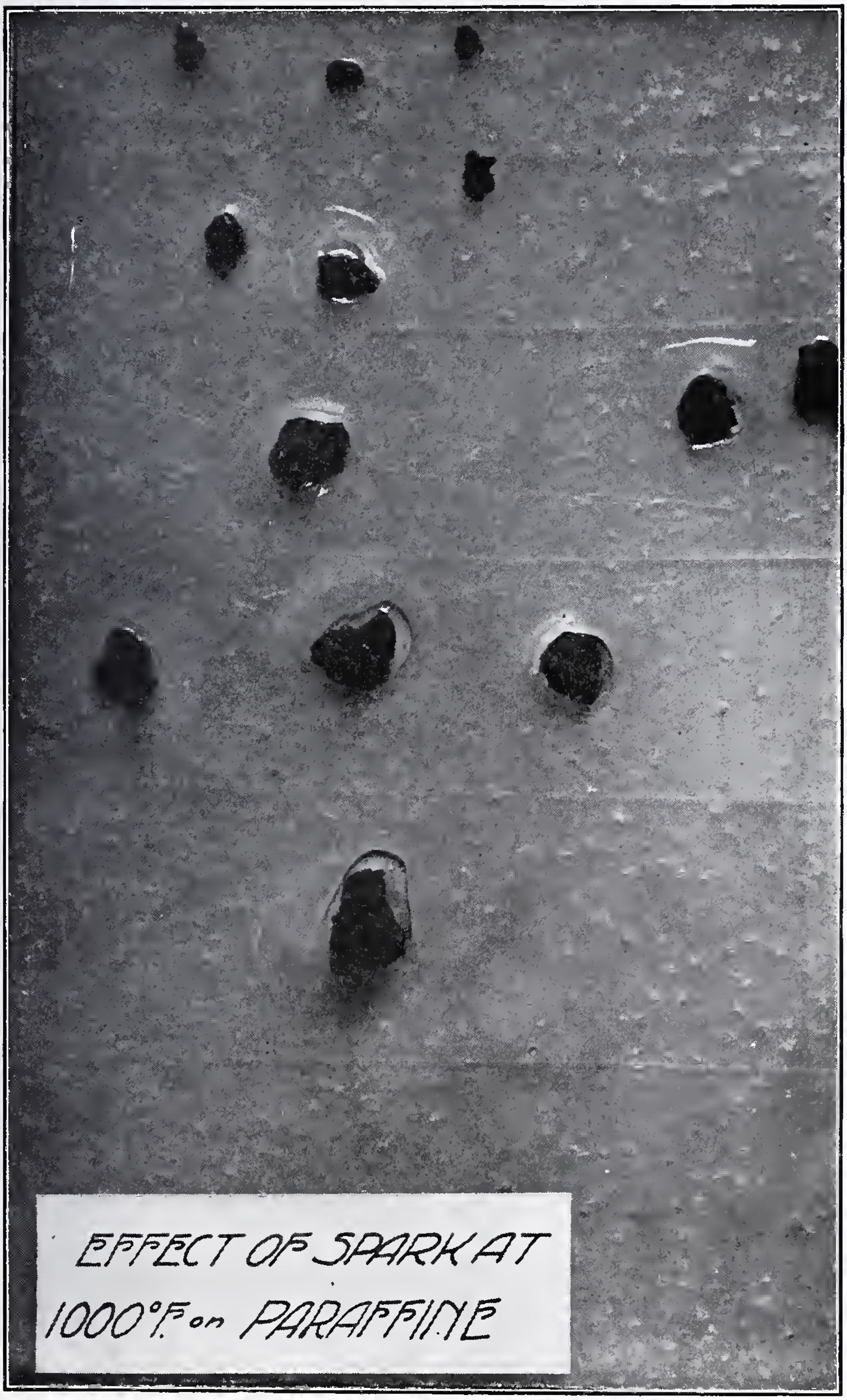

FIG. 46.—Effect of different size sparks at 1000° F. on paraffine.

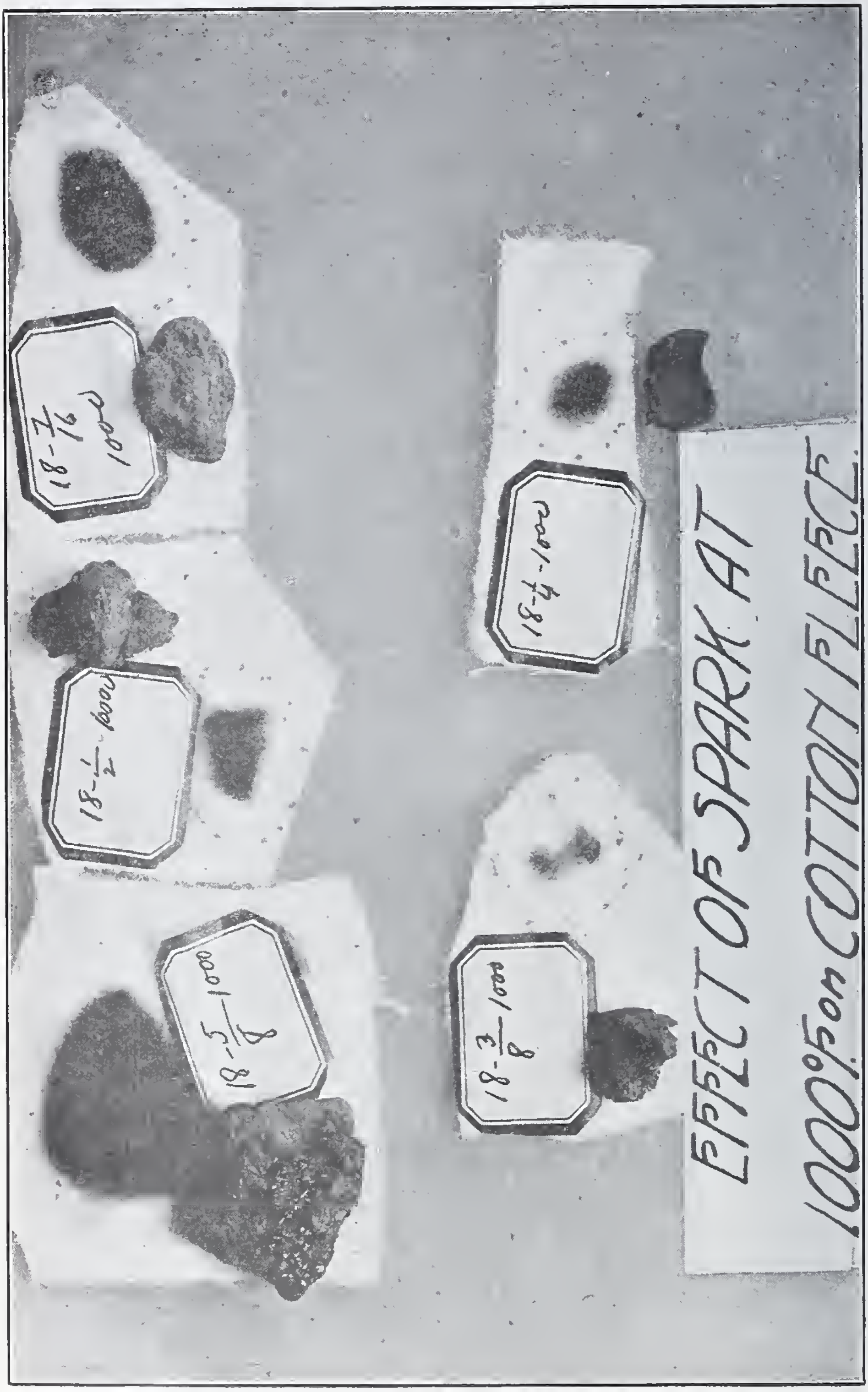

Fig. 47.—Effect of different size sparks at 1000° F. on cotton fleece.

(g) Sparks at 1200° F.—The paraffine began to boil and simmer when sparks at this temperature struck it. Distinct troughs were formed around the larger ones, as shown by Figure 50. The cotton fleece began to give off smoke in the case of the large sparks, and the small ones scorched it rather decidedly. This latter fact is shown by Figure 51. The excelsior was charred by all the sparks and also gave off smoke. The sparks themselves were a more distinct dull red than in the previous test.

(h) Sparks at 1300° F.—At this temperature all of the sparks so badly melted the paraffine that they immediately settled to the bottom of the pan. The size of the troughs around the sparks is very distinctly shown in the photographic illustration, Figure 52. The cotton fleece in the case of each size spark was very decidedly charred, as indicated by Figure 53. In fact, the charring amounted to a virtual burning of the fleece, for actual flashes of blaze now became noticeable. The excelsior charred and smoked, and for the larger sparks, developed a slight burning of separated fibres. The sparks proper were a distinct red, almost glowing. It is evident that the temperature zone is being reached at which sparks really may become a fire menace.

(i) Sparks at 1400° and 1500° F.—The effect of sparks heated to these temperatures, and, in fact, temperatures up to 1800° on paraffine was no longer accurately determinable on account of the severe melting, as shown in Figures 54 and 55. The cotton fleece was actually ignited so that it burned slowly. Figure 56 gives an indication of this fact. Figure 57 shows the effect of sparks at these temperatures on excelsior. In most cases this actually sparked or flashed. The dry grass, however, only smoked and charred.

(j) Sparks at 1600° to 1800° F.—The paraffine tests at these temperatures showed large melted areas around all sparks, large or small, as shown by Figures 58, 59 and 60. At 1600° the cotton fleece was ignited and flashed with $7/16$ inch sparks. This was more markedly true, especially with smaller sparks, at 1700° and 1800°. Figure 61 illustrates these results.

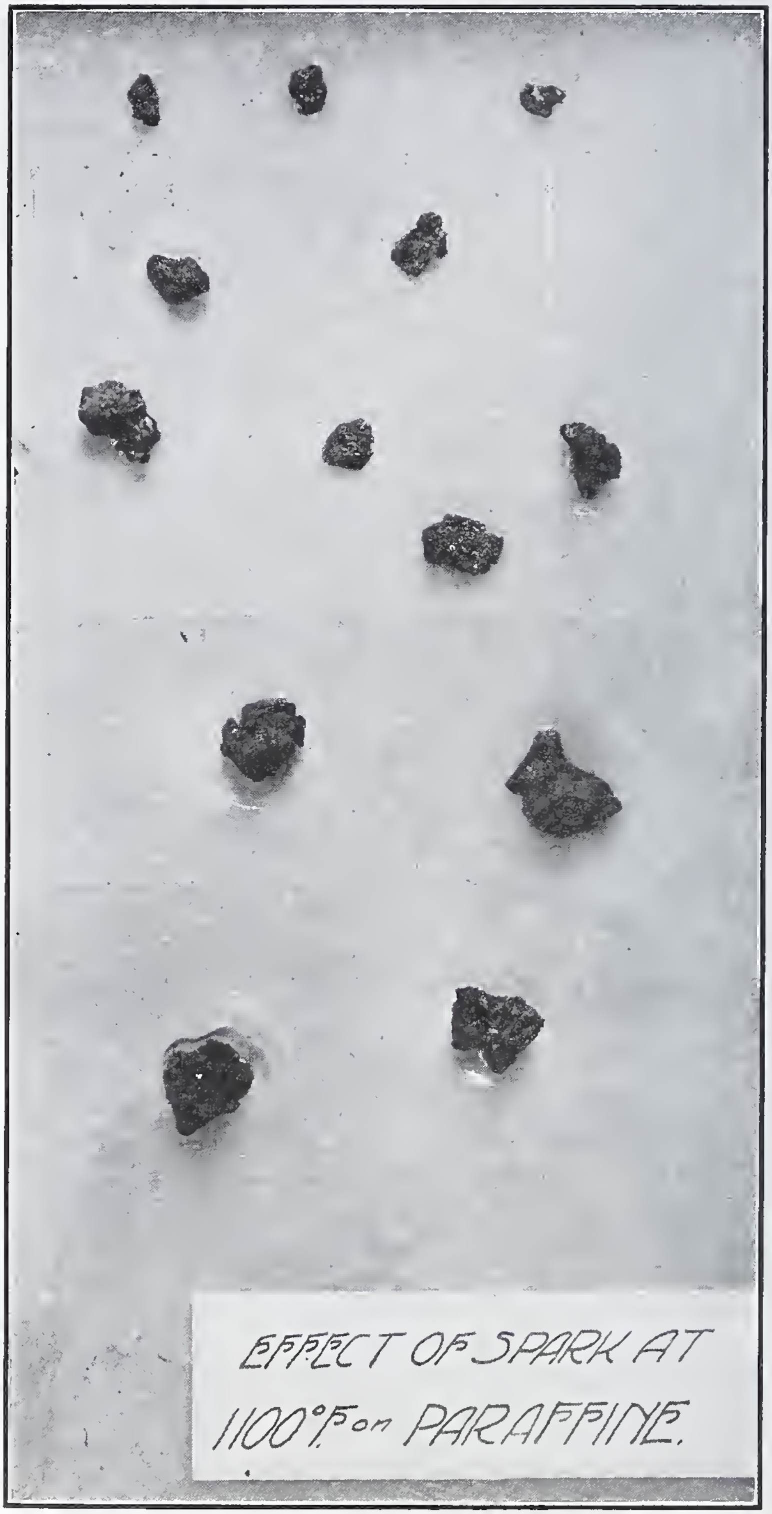

Fig. 48.—Effect of different size sparks at 1100° F. on paraffine.

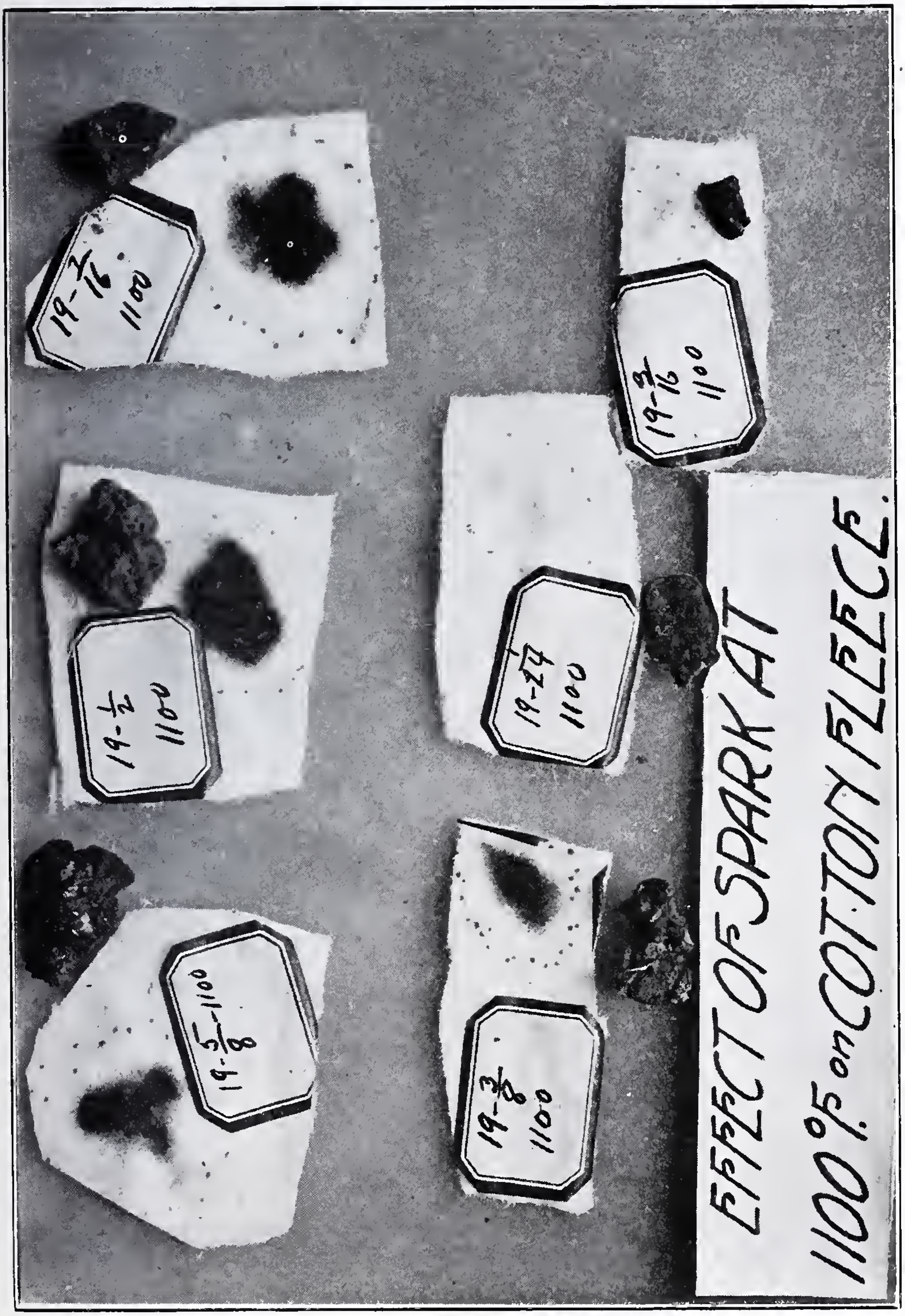

FIG. 49.—Effect of different size sparks at 1100° F. on cotton fleece.

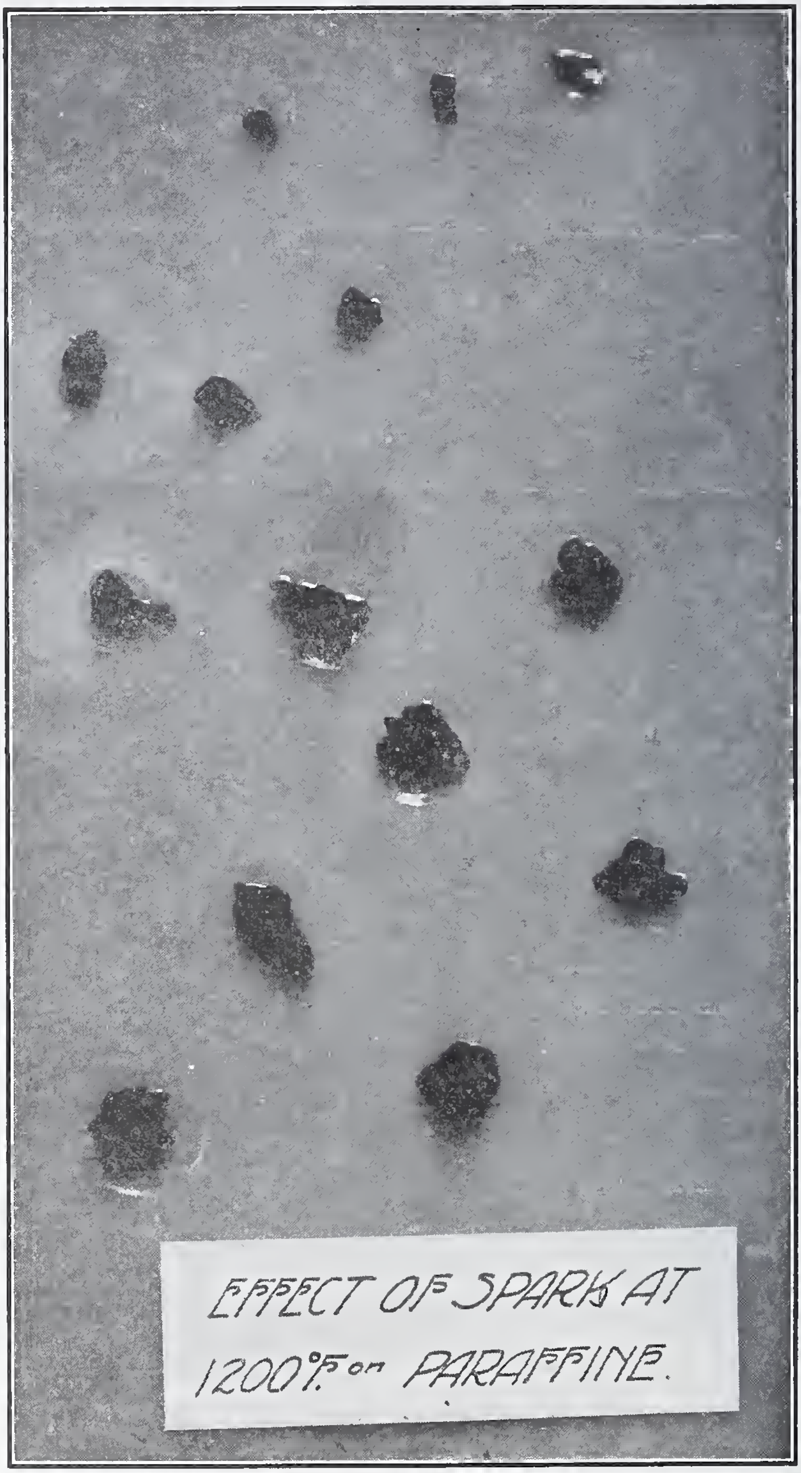

Fig. 50.—Effect of different size sparks at 1200° F. on paraffine.

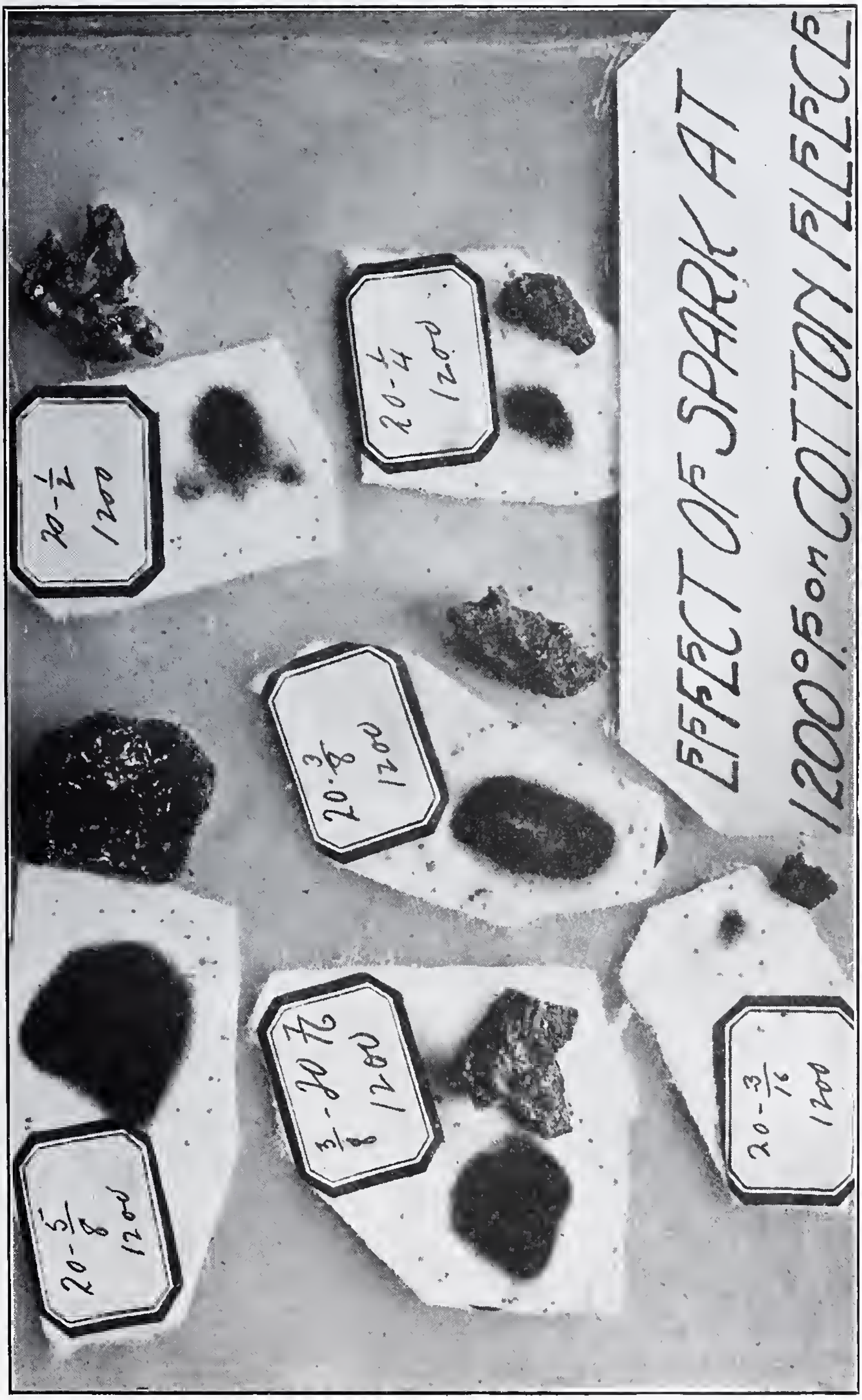

Fig. 51.—Effect of different size sparks at 1200° F. on cotton fleece.

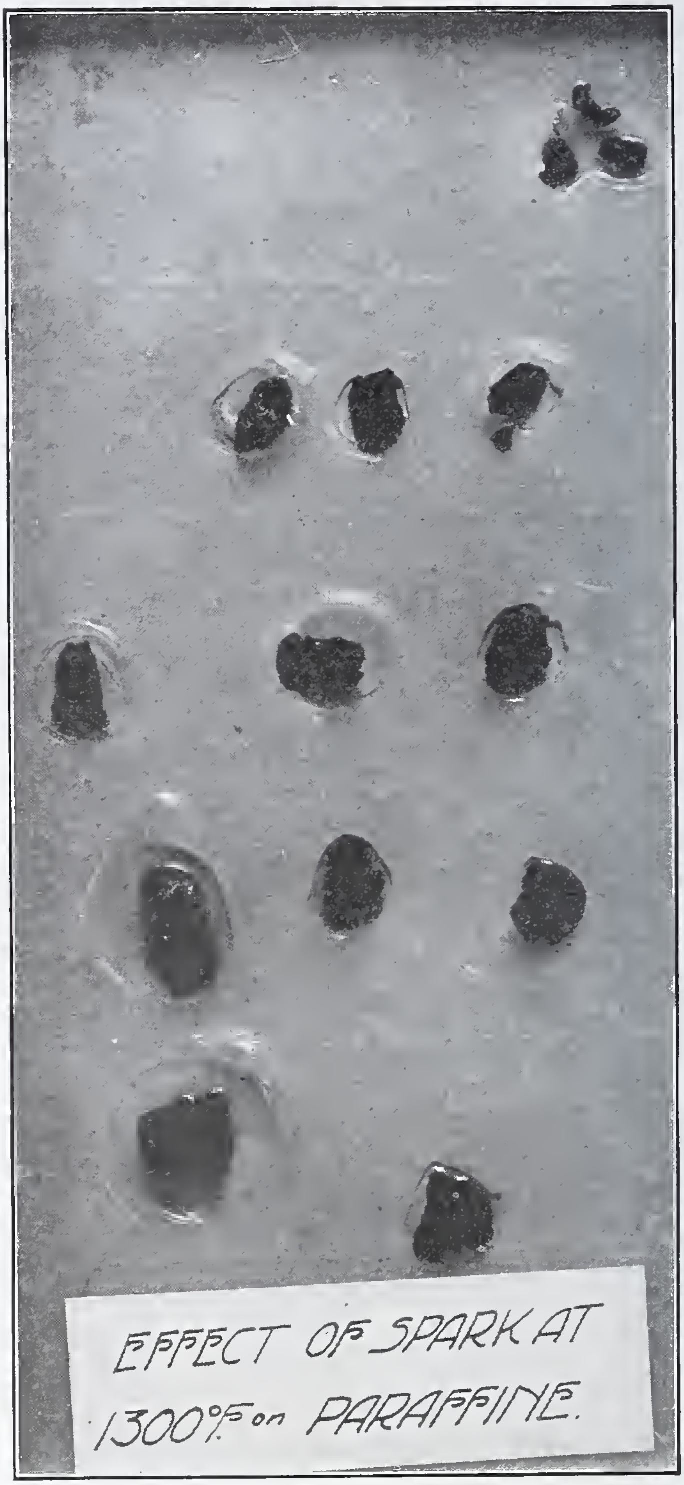

Fig. 52.—Effect of different size sparks at 1300° F. on paraffine.

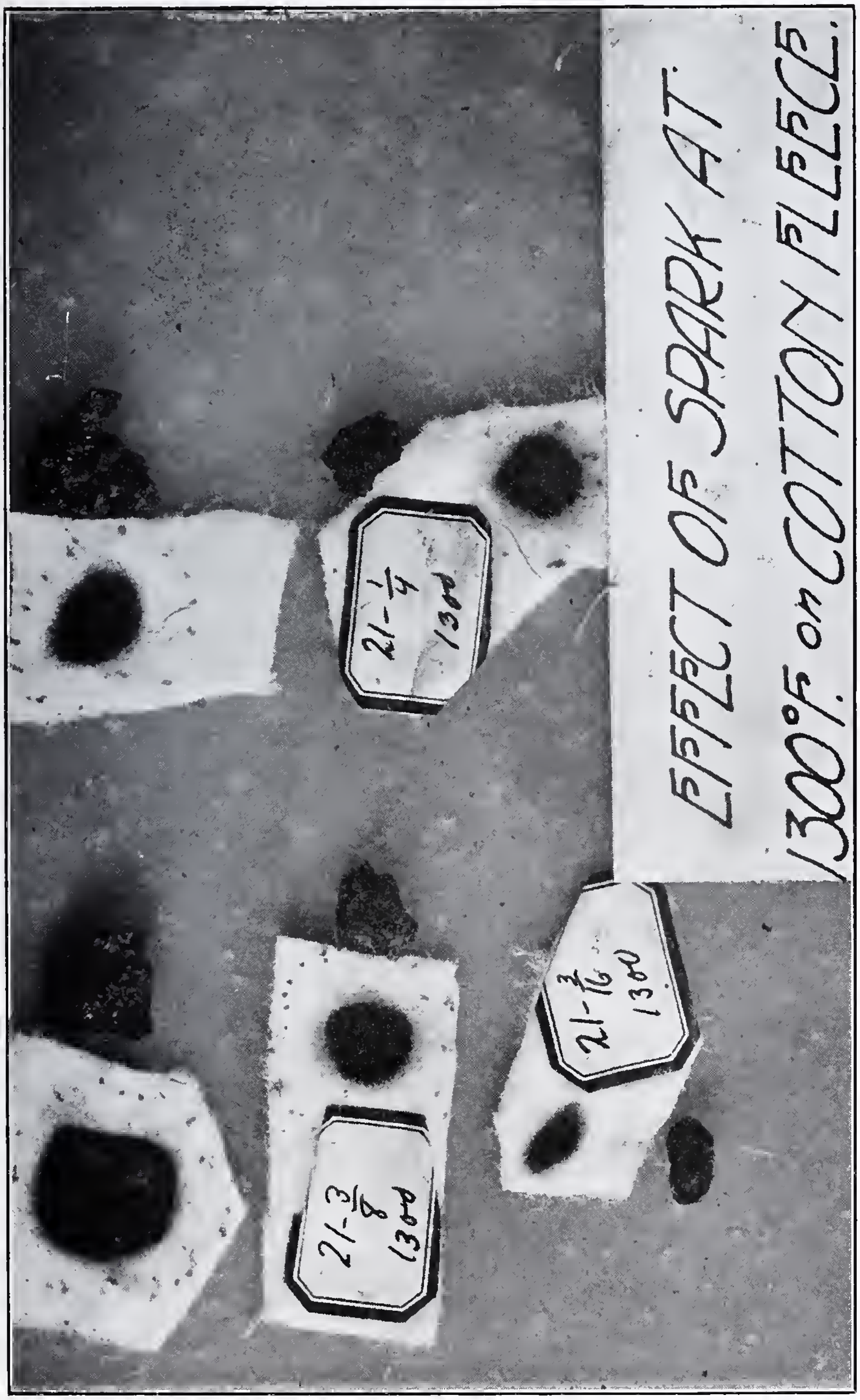

FIG. 53.—Effect of different size sparks at 1300° F. on cotton fleece.

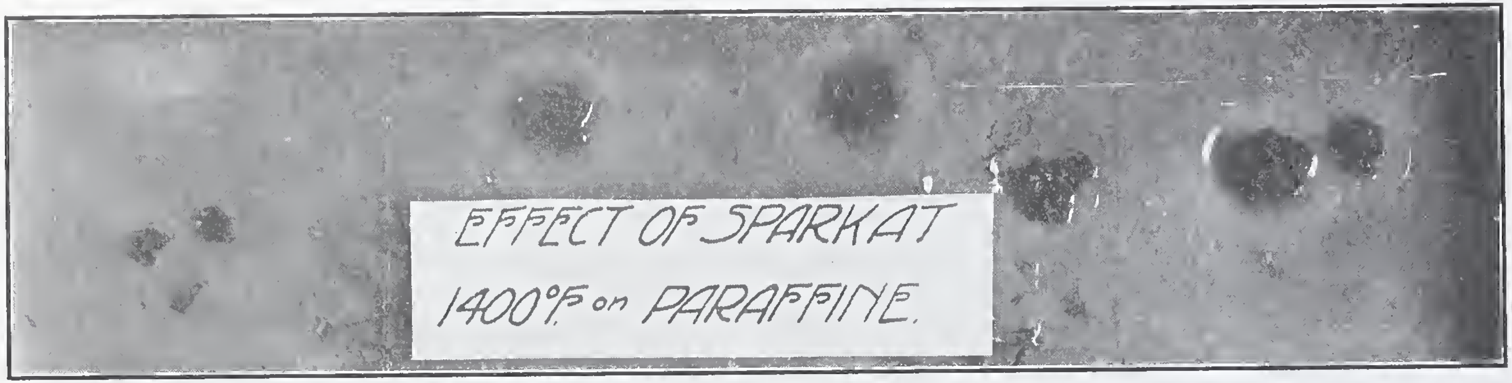

Fig. 54.—Effect of different size sparks at 1400° F. on paraffine.

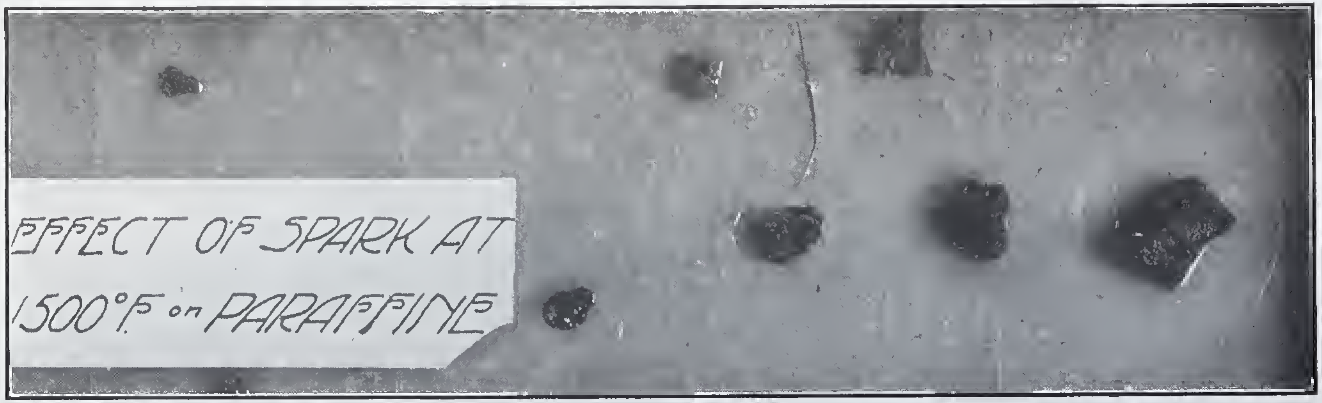

Fig. 55.—Effect of different size sparks at 1500° F. on paraffine.

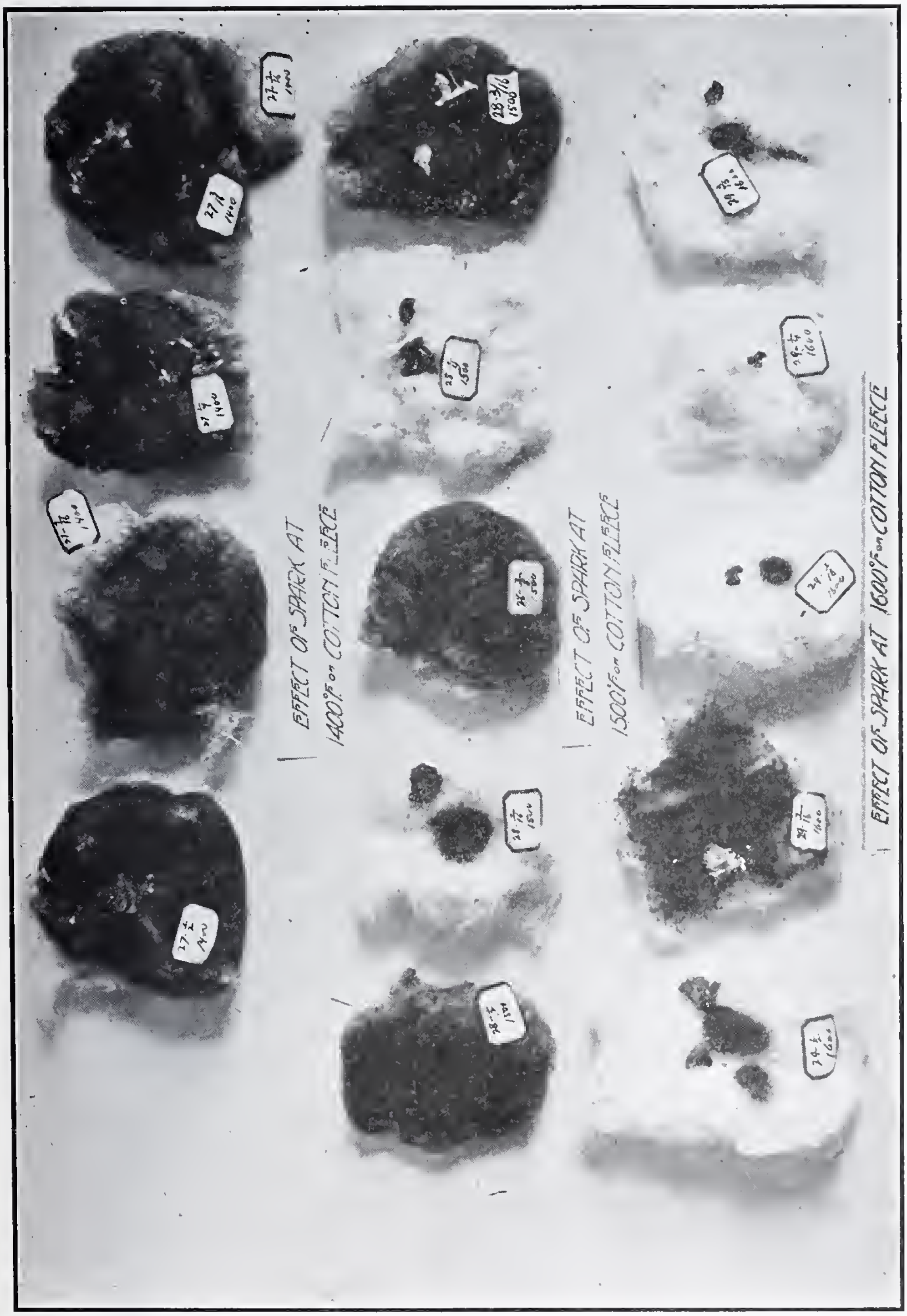
EFFECT OF SPARK AT 1400°F on COTTON FLEECE
EFFECT OF SPARK AT 1500°F on COTTON FLEECE
EFFECT OF SPARK AT 1600°F on COTTON FLEECE

FIG. 56.—Effect of different size sparks at 1400°, 1500°, and 1600° F. on cotton fleece.

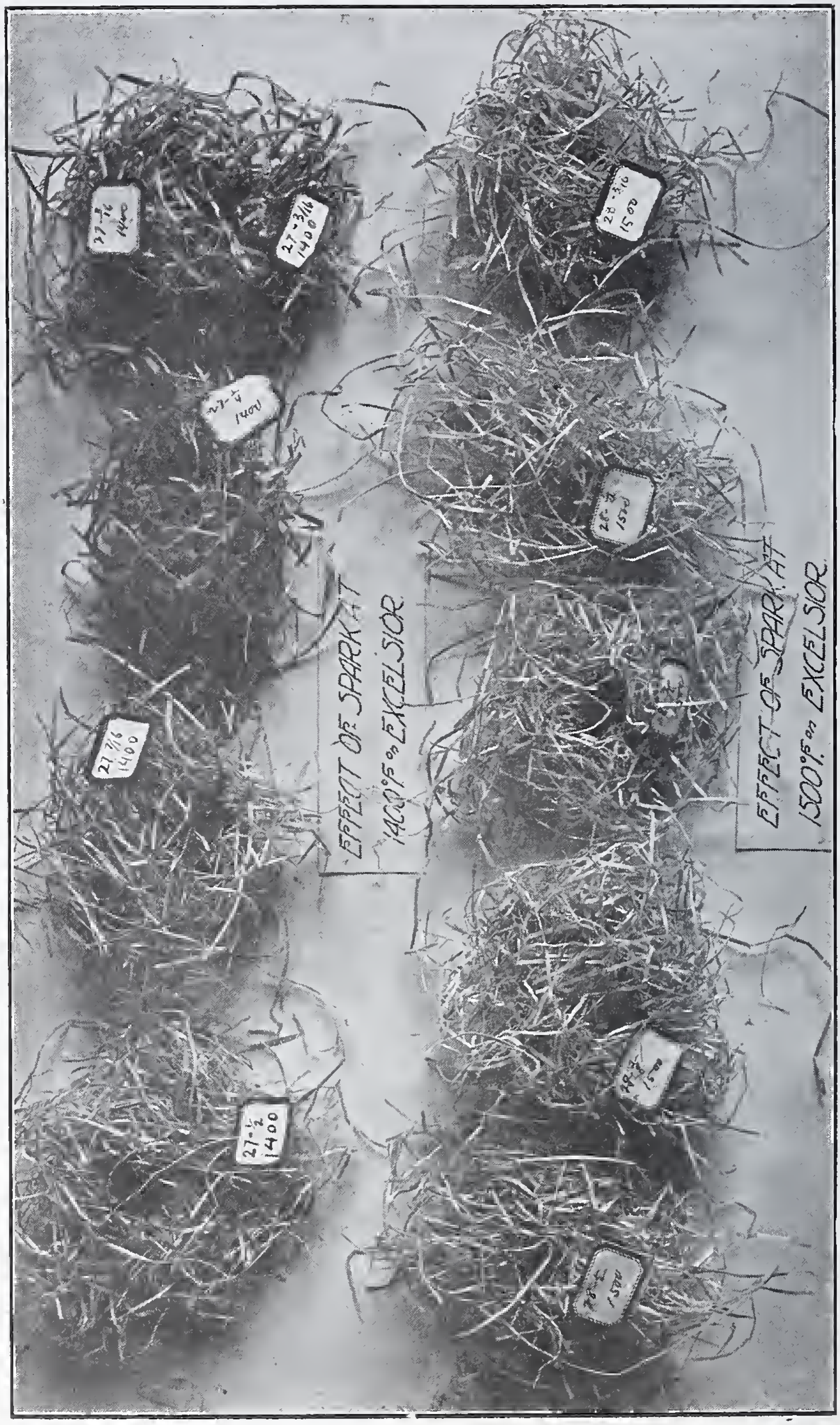

FIG. 57.—Effect of different size sparks at 1400° and 1500° F. on excelsior.

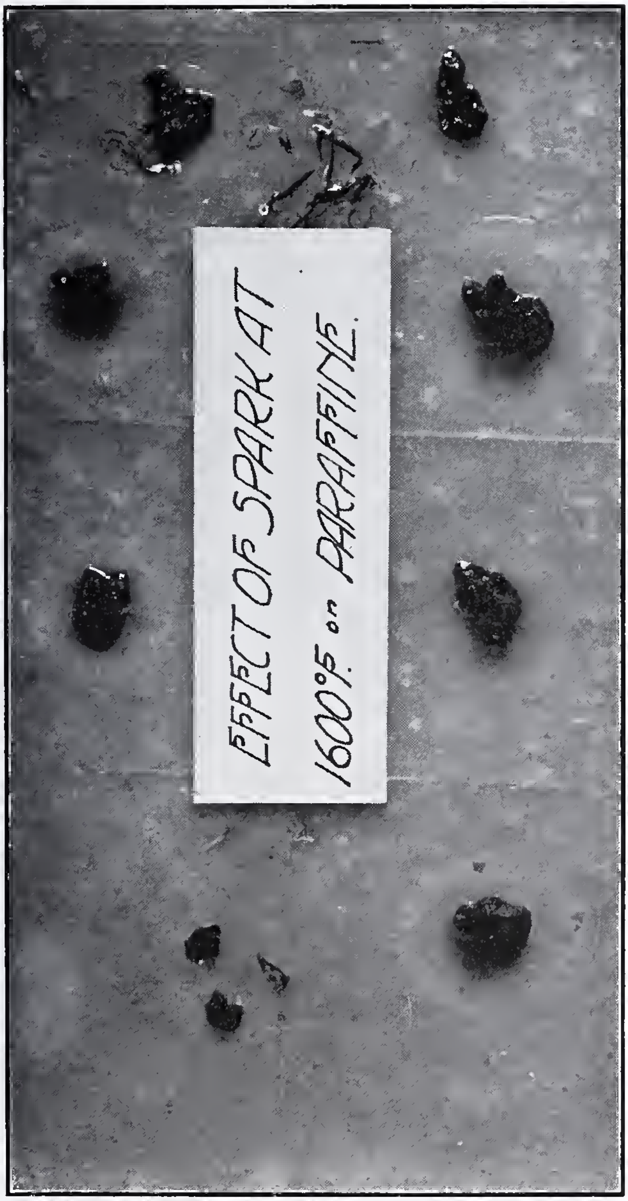

Fig. 58.—Effect of different size sparks at 1600° F. on paraffine.

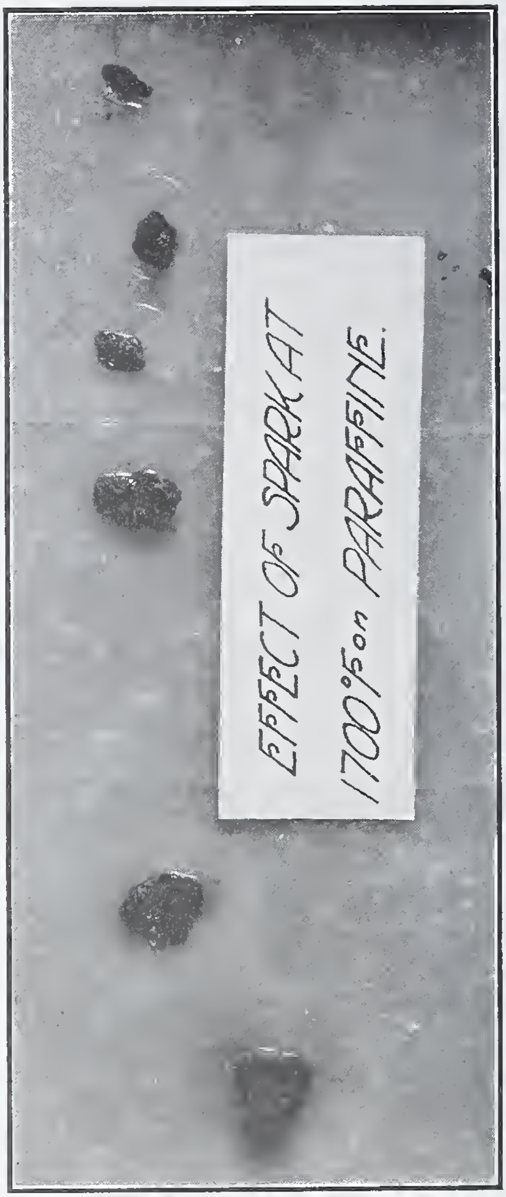

Fig. 59.—Effect of different size sparks at 1700° F. on paraffine.

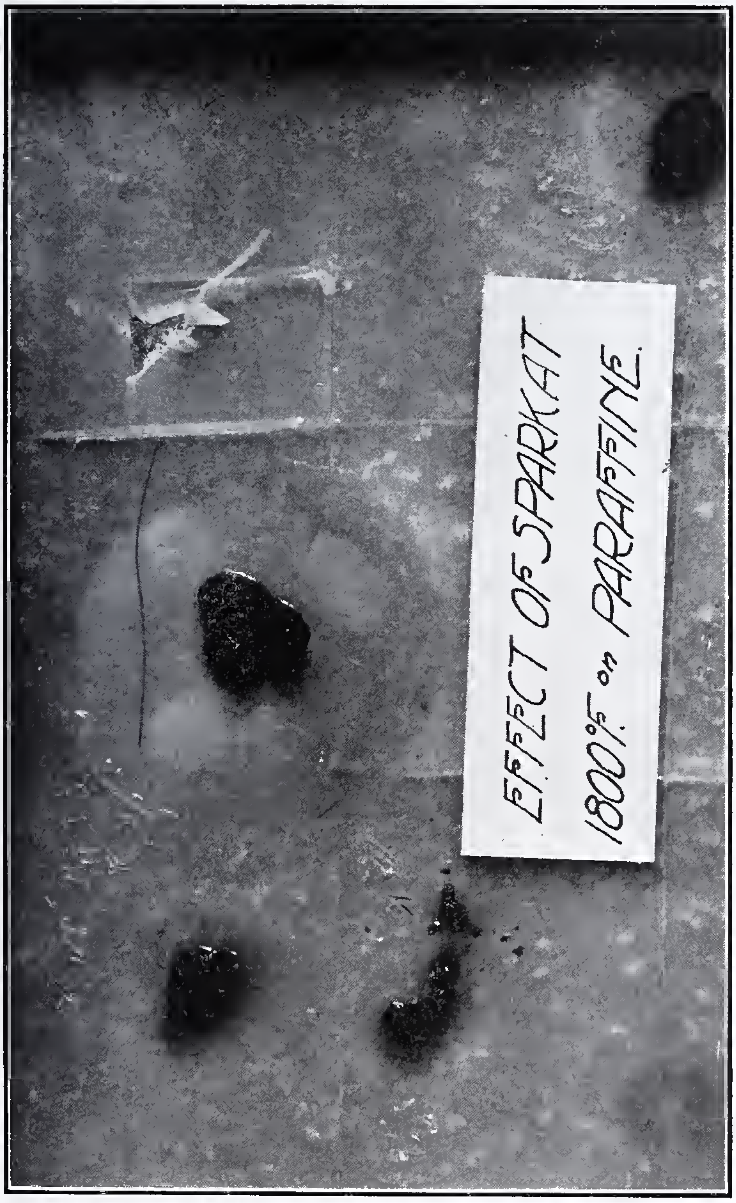

Fig. 60.—Effect of different size sparks at 1800° F. on paraffine.

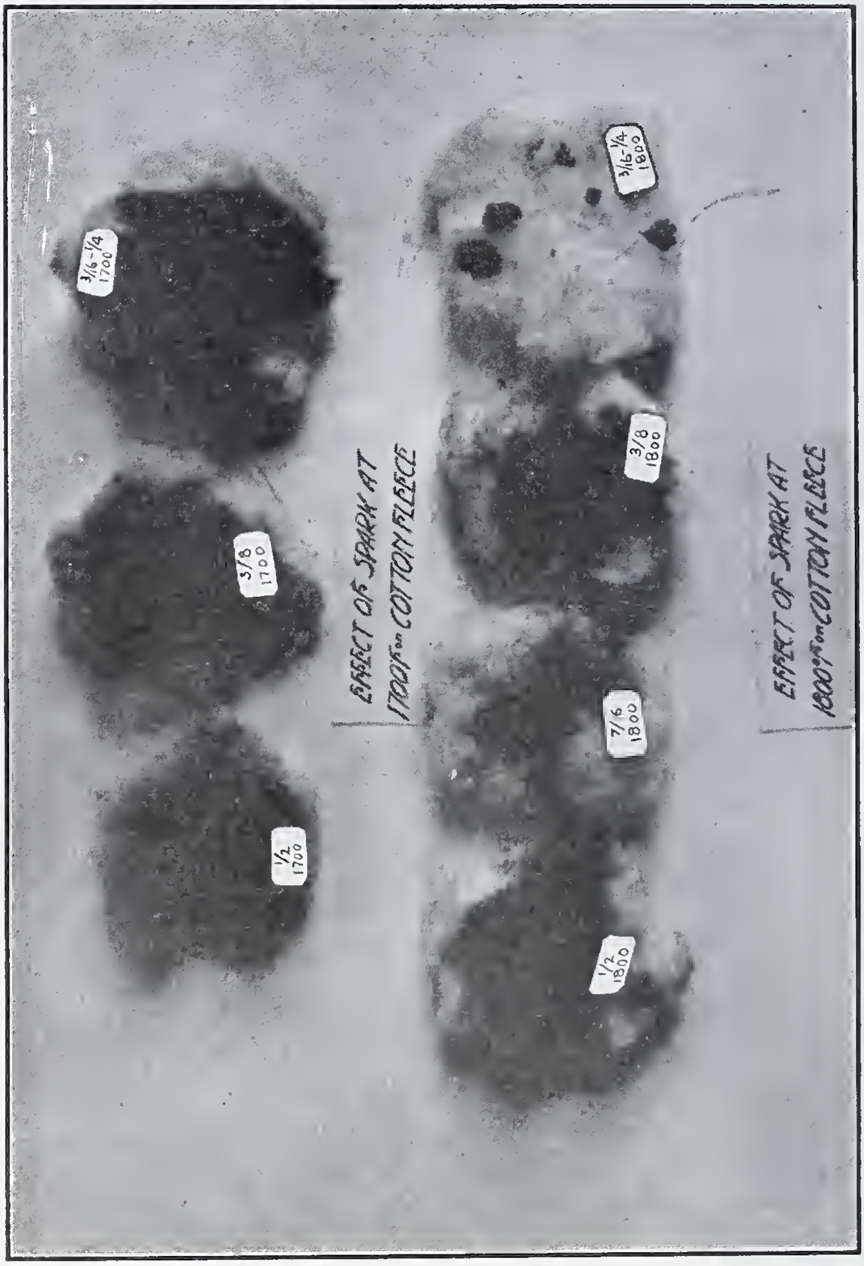

Fig. 61.—Effect of different size sparks at 1700° and 1800° F. on cotton fleece.

At 1600° the excelsior did not start to burn, but it did spark. Figure 62 shows the absence of burning. At 1700°, however, a small area was ignited by the larger sparks and burned for a few seconds. At 1800° the entire excelsior specimen was consumed when the largest sparks were dropped on it. The smaller sparks only caused slight flashing or "sparking."

A valuable and interesting record is presented by Figure 63, which shows the results obtained by dropping the sparks heated from 1400° to 1800° upon dried grass. Apparently ordinary dried grass is not so inflammable as either excelsior or cotton fleece under the conditions of these tests, for only in two instances did the grass actually blaze up, and that was when the large sparks, 7/16 inch and 1/2 inch, respectively, were dropped on it. The area burnt, however, was entirely local, no tendency existing for the blaze to spread.

**5. Conclusions as to the Ignition Powers of Sparks.**—It is evident from the foregoing test results that temperature and size, each play an important part in the aptitude with which locomotive sparks may set fire to ordinary combustible materials. A summary of the observations made and conclusions reached may be stated as follows:

1. It is only when the temperature of sparks reaches 1000° that they begin to possess the power to ignite combustible materials. At temperatures near the 1000° lower limit this fact is confined to the larger sparks, those 1/2 inch or greater in size.

2. It is only the larger sparks, 7/16 inch to 5/8 inch, abnormal in size, that become a menace between 1000° and 1400°.

3. At temperatures beyond 1400° with stimulating air currents the chances seem fair to start a fire if a spark of sufficient size comes in contact with dry combustible material in a properly loose and divided state, such as dead grass and pine needles. The experimental data shows, however, that a spark, to possess the faculty of keeping "alive" long enough to do this upon reaching the ground, must be larger than 1/4 inch. Smaller sparks, when heated above 1400° showed a tendency to burn themselves out so that they virtually amounted to ash before they travel far.

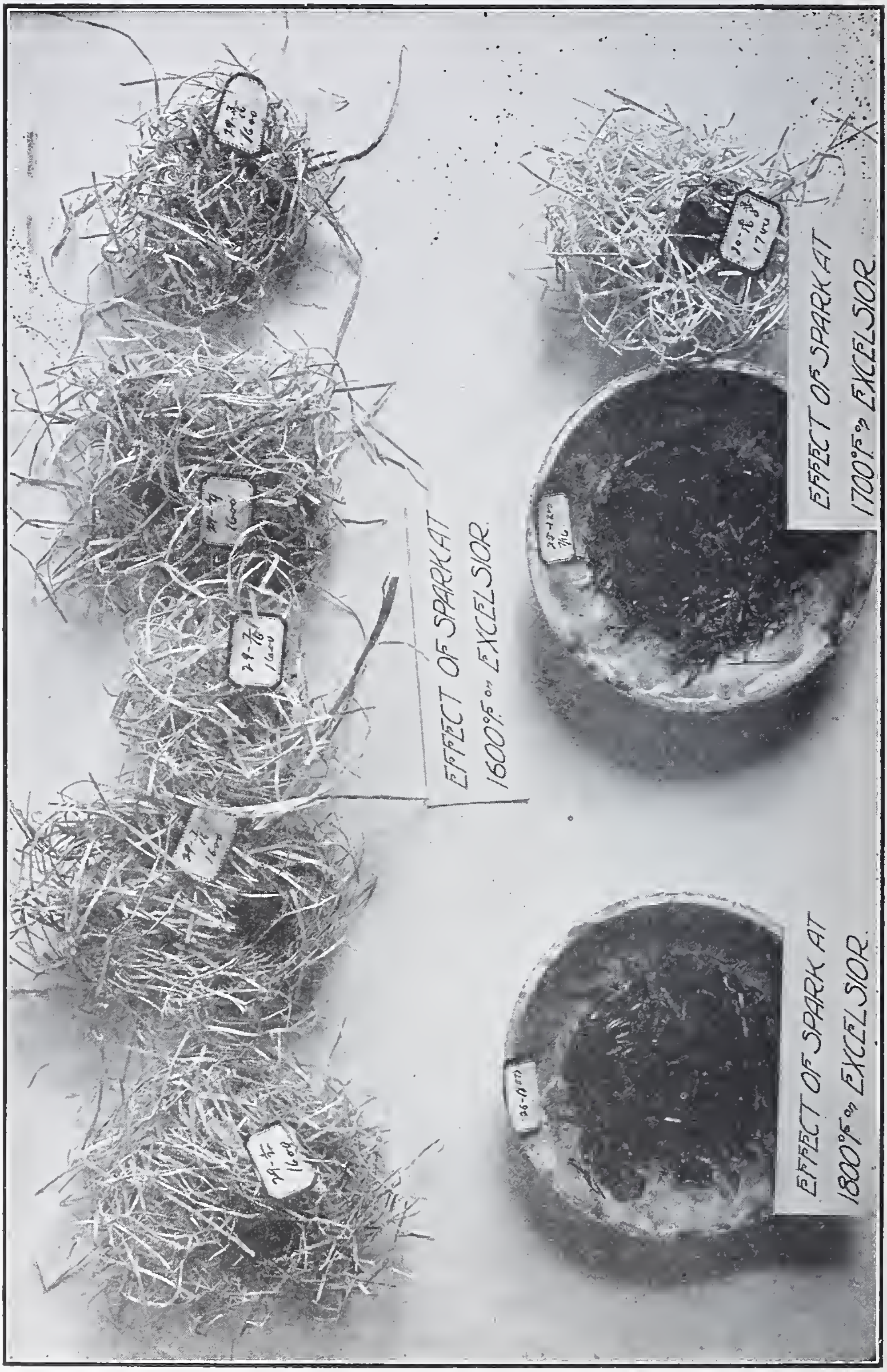

Fig. 62.—Effect of different size sparks at 1600°, 1700° and 1800° F. on excelsior.

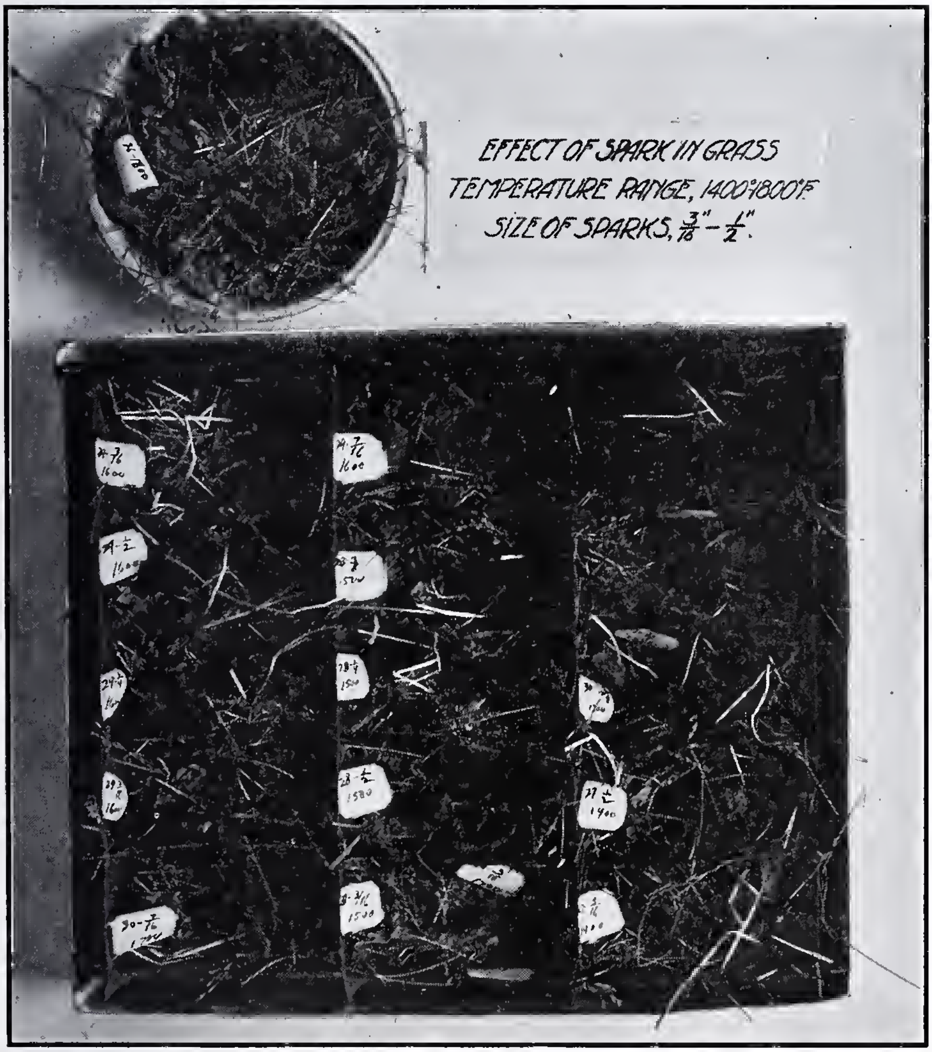

Fig. 63.—Effect of different size sparks at a temperature range from 1400° to 1800° F. inclusive.

# CHAPTER VIII

## DISTRIBUTION OF LOCOMOTIVE SPARKS

A complete analysis of the fire-starting characteristics of locomotive sparks falls into two divisions. The consideration of the igniting powers of the individual sparks and the circumstances and conditions which affect these properties compose the first division of this analysis. The second covers the experimental and theoretical study of the phenomena of spark distribution along the right of way. It is this second phase of the spark problem with which this chapter proposes to deal.

**1. Early Experiments with Exhaust Jet and Spark Distribution within Front End.**—An investigation of locomotive spark distribution, to be complete, must really begin with the action of the exhaust jet and the distribution of the sparks within the front end proper. The American Railway Master Mechanics Association,[1] as already pointed out, has had a committee make an investigation of the draft characteristics of the front end. Included in this investigation was a careful study of the action and character of the exhaust jet, especially from the point of view of spark material elimination. At the same time, Dr. W. F. M. Goss, who made these investigations at the locomotive laboratory of Purdue University, took occasion to study the distribution of the sparks within the front end. It will not be necessary here to repeat the description of the experiments mentioned above or the analysis of the results secured. All of this has been well presented by Dr. Goss in his treatise on Locomotive Sparks.[2] His conclusions, however, may be briefly summarized as follows:

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[1] Report on Exhaust-pipes and Steam-passages, American Railway Master Mechanic's Association, Proceedings, 1896, pp. 58–143.

[2] "Locomotive Sparks," Chapter V, "Action of Exhaust Jet and Distribution of Sparks within the Front End," pp. 74–88.

First, the experiments disproved the idea that the jet of steam fills the stack at or near the bottom, or that the action of the exhaust jet is similar to that of a pump, i.e., that each exhaust supplies a ball of steam, which fills the stack very much as the piston of a pump fills a cylinder. On the contrary, the action of the jet is such that under conditions common to practice it flows steadily from the exhaust pipe tip, touching the stack only when it is near the top. It thus acts (1) to induce motion in the particles of gas which immediately surround it, and (2) to enfold and entrain the gases, which are thus made to mingle with the substance of the jet itself.

Second, the observations made showed that there is some intermingling of the smoke box gases with the steam of the jet. However, it does not appear that this intermingling is necessarily so complete that the exhaust steam might reasonably be expected to act as a thorough spark-cooling or extinguishing agent.

And, third, the conclusion reached concerning the distribution was that the sparks follow most readily those portions of the stream issuing from the stack which have the lowest velocity.

**2. Early Experiments to Determine Spread of Locomotive Sparks Along the Right of Way.**—These experiments are also described in full by Dr. Goss in his book on Locomotive Sparks.[1] One of the outstanding contributions of the early tests was the development of methods of procedure. All subsequent experiments in this field have followed the original procedure and elaborated upon it. Thus, for instance, the idea of employing flat, shallow pans with cotton evenly distributed over the bottom of each for catching sparks and recording their heat content by noting their scorching effect, was developed in the course of these experiments. In subsequent investigations other materials, such as dry grass, excelsior, and dry pine needles, were also used for field work, but paraffine seems to have proven most desirable as a registering medium.

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[1] Ibid, Chapter VI, "Spread of Sparks from Locomotives as Disclosed by Observations along the Right of Way," pp. 89–128.

These early tests also resulted in the working out of an excellent method for presenting graphically the distribution of sparks on the ground at right angles to the track. This procedure has been employed in all the field tests made since, thus linking up the results of the early tests with the results of those which have followed.

Lastly, the theoretical considerations affecting the spread of sparks from locomotives, taking into consideration wind effects, were also developed.[1] In order to do this intelligently, the effect of gravity in accelerating the fall of sparks had to be determined experimentally. This was done in a very ingenious way as described in Chapter VII of Dr. Goss's book.[1] The average value of the acceleration of gravity in feet per second for locomotive sparks was found to be 22.72.

A summarized statement of results of the field experiments referred to above, as prepared by Dr. Goss, is as follows:[2]

"1. The greatest number of sparks fell at from 35 to 150 feet from the center of the track. It may therefore be assumed, from the data at hand, that the possibility of fire is greatest within these limits.

"2. With a few exceptions, the pans nearest the track, i.e., from 15 to 20 feet, caught but few sparks. Local conditions, due to air-currents about the train, may in part be responsible for this.

"3. No scorching of the cotton in the pans was in any case observed. This may be accounted for by the fact that during the time the tests were run (in April and May) the temperatures were comparatively low. Some of the larger sparks were quite warm, however, when picked up immediately after falling.

"4. Beyond 125 feet from the center of the track the sparks were of such character as to preclude any possibility of fire from them.

"5. In March, preceding the tests, when a light crust of snow covered the ground, it was possible to trace evidence of dust from passing locomotives at a distance of 800 feet from the track. The wind velocity was high—about 20 miles an hour. Nothing in this observation should be interpreted as in conflict with the statement of the preceding paragraph."

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[1] Ibid., Chapter VII, "Theoretical Considerations Affecting the Spread of Sparks by Moving Locomotives," pp. 129–144.

[2] Ibid., Chapter VI, p. 128.

**3. Subsequent Field Experiments.**—It has been indicated at length in Part I of this treatise that the entire locomotive spark problem, because of growing railway operating expenses, greater public regulation, stricter law enforcement, and the necessity for better locomotive performance, has been given more and more intensive study and consideration. Among other things, the necessity became evident for knowing more about the career of the locomotive spark after leaving the stack than was revealed by the epoch-making tests of Dr. Goss. The result was, that several of the railroad companies and the engineering staff of Purdue University made it possible to conduct further comprehensive and valuable field tests. The important ones among these may be listed as follows:

The Monon Tests, made for the Chicago, Indianapolis & Louisville Railway by Prof. Gilbert A. Young and the author, 1914.

The Lake Erie & Western Railroad Tests, made in connection with thesis work, under the direction of the author at Purdue University, 1915.

The Cotton Belt Tests, made by the author for the St. Louis & Southwestern Railroad, at Pine Bluff, Arkansas, 1918.

The Big Four Tests, made by the author on the Cleveland, Cincinnati, Chicago & St. Louis Railroad, 1920.

Each one of these tests, together with results secured, will be treated separately and in detail.

## I. THE MONON TESTS

These tests were conducted for the purpose of determining the quantity and size of sparks ejected; how far these sparks traveled after leaving the locomotive; and what their igniting powers were when they struck the ground. A short portion of the main line of the Chicago, Indianapolis and Louisville Railroad was selected just north of Lafayette, Indiana, over which the tests were run. The grade which the test locomotives were

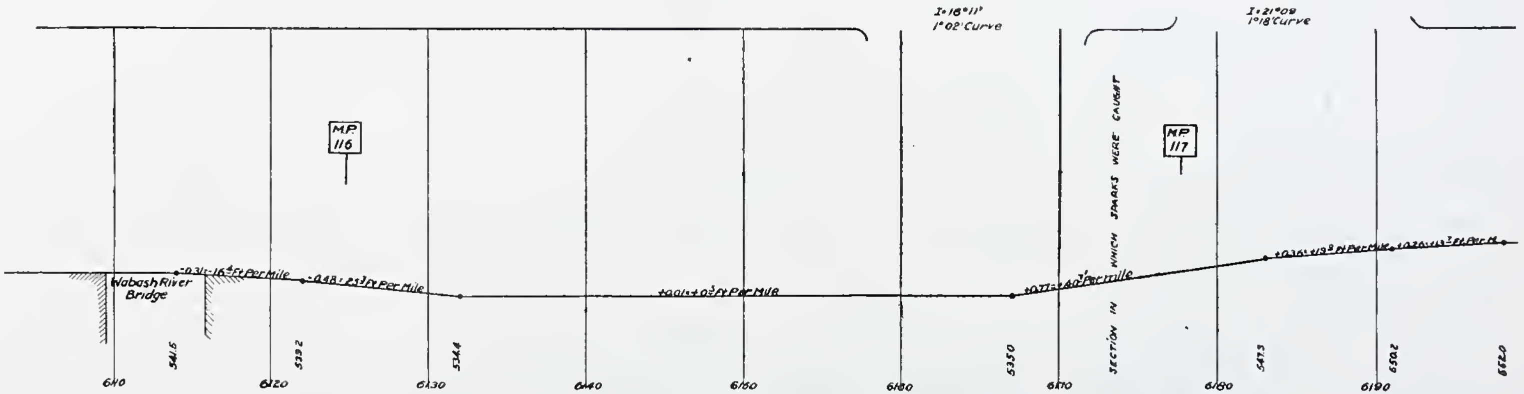

Fig. 64.—Profile of test track at Lafayette, Indiana. Monon Tests.

required to ascend equaled 40.7 feet per mile, or .77%. The profile of the test stretch is shown in Figure 64.

Two locomotives were employed, one, Monon No. 66, was of the American, or 4-4-0 type. Its cylinders were 18″ × 24″; drivers 67 inches in diameter; total weight, 100,000 pounds; tractive force, 15,800 pounds. It used saturated steam and was equipped with a standard "Master Mechanics" front end. The front end netting employed was square mesh, 2½ × 2½.

The other was also a saturated steam locomotive, Monon No. 9, with wheel arrangement 0-6-0; cylinders, 18″ × 22″; drivers 45 inches in diameter; total weight, 88,000 pounds; and tractive power, 20,100 pounds. Its front end arrangement was similar to that of Locomotive No. 66.

**4. Test Preparations.**—In preparation for the tests a plot of ground was laid off on each side of the track as shown in Figure 65. Five rows of stakes, 20 feet apart, were set at right angles to the track and numbered as shown in the figure. The rows parallel to the track were eleven in number, the first one of which, *A*, was 25 feet from the center of the track, the balance extending back to 350 feet at intervals of 20, 25 and 50 feet, respectively. The total number of pan stations thus established equalled 55, and the area of ground over which the sparks were collected equaled 28,000 square feet, or approximately two-thirds of an acre.

Pans were prepared, 12 inches square and ⅜ inch deep. A sufficient number of pans for four rows perpendicular to the track, i.e., 44 in all, were filled with paraffine to at least ¼-inch depth, and the balance, 11 in number, sufficient for one row perpendicular to the track, were lined with cotton fleece. A picture of the staked-out test ground properly equipped with pans is shown in Figure 66.

In addition to the foregoing equipment other necessary apparatus was employed for the purpose of determining wind velocities and direction and locomotive running speeds. An observer in the cab recorded the throttle and reverse lever positions and noted the character of the smoke.

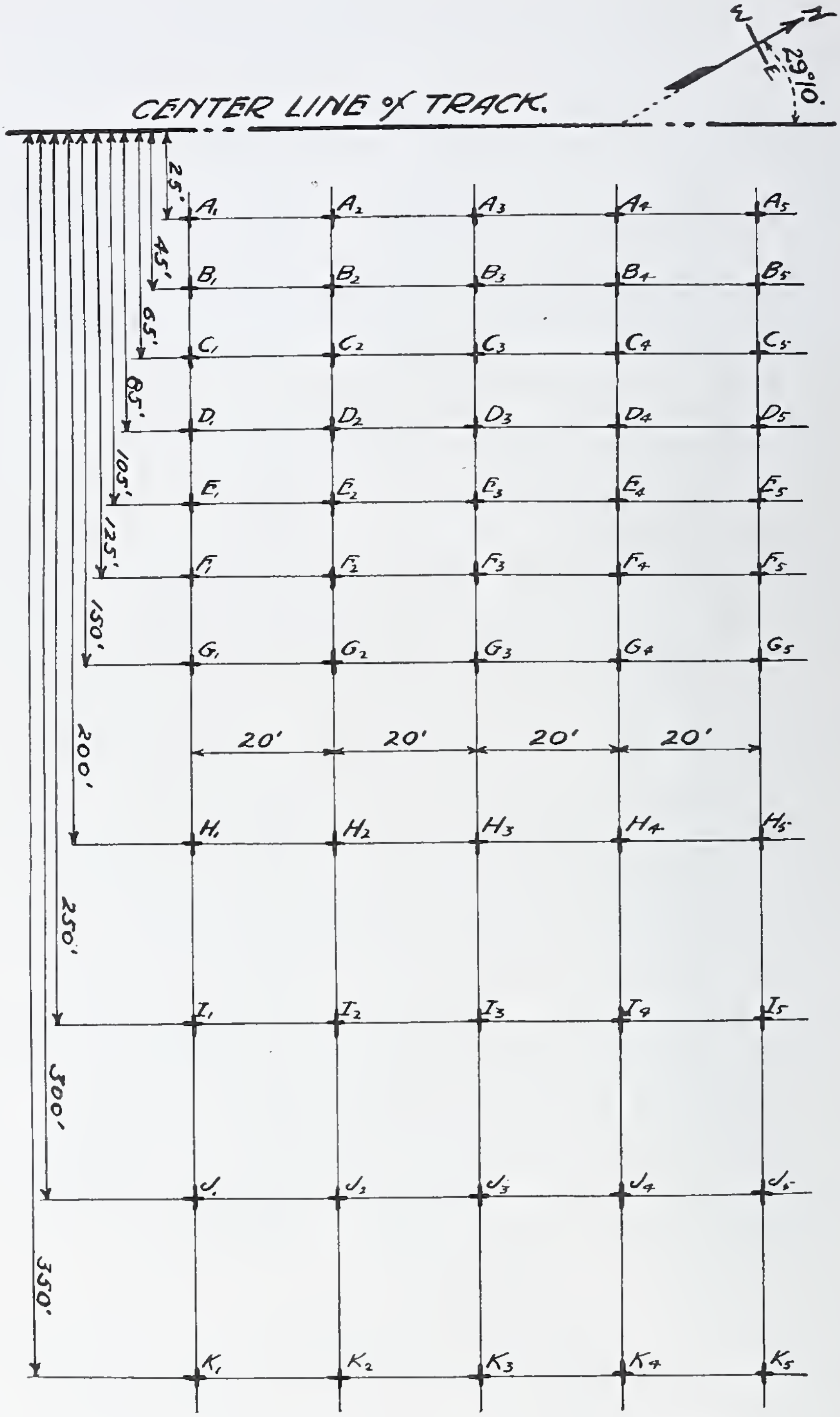

Fig. 65.—Layout used to catch sparks. Monon Tests.

**5. Method of Testing.**—In conducting the tests an effort was made to run the locomotives by the pans at four different speeds, varying between an average low speed of 5 miles per hour and the maximum speeds possible with each load. The lightest loading consisted simply of a caboose. The train loads increased approximately in 25% increments to the maximum. Under this arrangement, 32 tests in all were run.

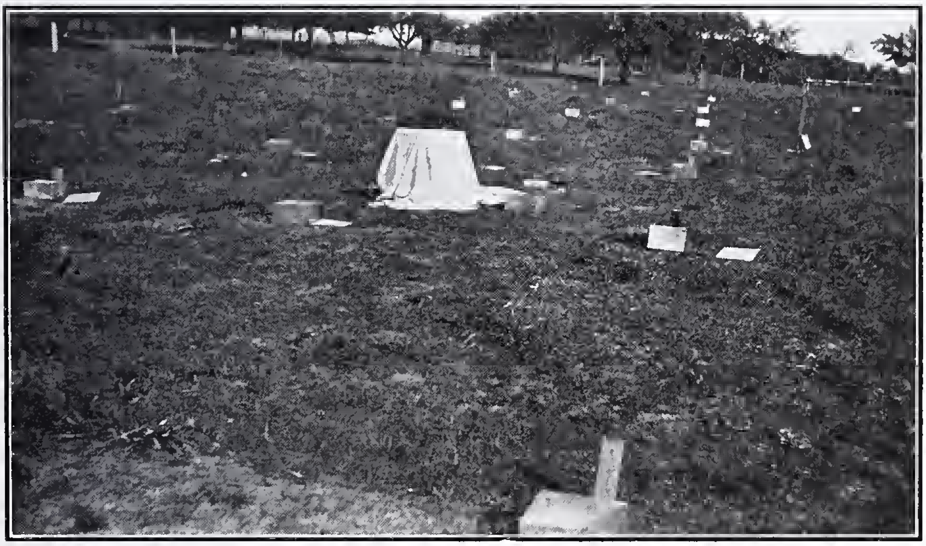

Fig. 66.—Staked and test ground equipped with pans. Monon Tests.

All the pans were kept covered until such time as the locomotive was ready to enter the test zone. Then the covers were quickly removed, and after the locomotive had passed and all sparks had time to settle the pans were covered over again and transferred to a specially prepared container. After noting the effect of the sparks which fell on the cotton fleece lined pans, the sparks of all pans were carefully placed in small bottles and labeled. One hundred and eighty-three such samples were collected during the course of these tests.

An effort was made during the tests to obtain data for the purpose of determining the influence of the wind at various velocities on spark distribution. However, during the tests

TABLE VIII.—MONON
General

| I | Test No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| II | Date of test | 8–22 | 8–22 | 8–22 | 8–22 | 8–22 | 8–22 |
| III | Hour | 10:37 a.m. | 10:55 a.m. | 11:15 a.m. | 12:30 p.m. | 12:45 p.m. | 1:00 p.m. |
| IV | Direction of wind | East | E. | E. | E. | E. | E. |
| V | Velocity of wind, M.P.H. | 4.20 | 5.20 | 4.90 | 6.17 | 6.17 | 6.17 |
| VI | Temperature, deg. F. | 79° | 79° | 79° | 78° | 78° | 78° |
| VII | Condition of weather | Clear | Clear | Clear | Clear | Clear | Clear |
| VIII | No. of cars | Caboose | Caboose | 12 | 9 | 9 | 9 |
| IX | No. of tons | ......... | ....... | 616 | 457 | 457 | 457 |
| X | Time req. pass meas. dist., sec | 17 | 13⅖ | 41 | 22⅗ | 22 | ....... |
| XI | Speed of train, M.P.H. | 21 | 27 | 9 | 16 | 17 | 8 app. |
| XII | Position of throttle | 6″ | 7 | Wide open | 10 | 12 | ....... |
| XIII | Position of reverse lever | 14 | 11 | Corner | 6 | 6 | ....... |
| XIV | Draft, inches of mercury | ......... | ......... | ....... | ....... | ....... | ....... |
| XV | Draft, inches of water | ......... | ......... | ....... | ....... | ....... | ....... |
| XVI | Character of smoke | Clear | Clear | Dark | Dark | Light | ....... |

TABLE IX.—MONON
General

| I | Test No. | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|
| II | Date of test | 8–26 | 8–26 | 8–26 | 8–26 | 8–26 | 9–9 | 9–9 |
| III | Hour | 3:45 p.m. | 4:00 p.m. | 4:45 p.m. | 4:50 p.m. | 5:20 p.m. | 11:20 a.m. | 11:50 a.m. |
| IV | Direction of wind | 60° | 60° | 60° | 60° | 60° | 15° | 15° |
| V | Velocity of wind, M.P.H. | 5.2 | 5.6 | 3.2 | 4.0 | 4.0 | 8.0 | 7.9 |
| VI | Temperature, deg. Fahr. | 72° | 70° | 70° | 68° | 68° | 78° | 80° |
| VII | Condition of weather | Clear | Clear | Clear | Clear | Clear | Clear | Clear |
| VIII | No. of cars | 11 | 11 | 9 | 9 | 9 | 5 | 5 |
| IX | No. of tons | 630 | 630 | 510 | 510 | 510 | 350 | 350 |
| X | Time req. pass meas. dist., sec | 25 | 43⅕ | 23⅖ | 46⅘ | 36⅖ | 24⅕ | 84⅘ |
| XI | Speed of train, M.P.H. | 14 | 8.6 | 15 | 7.8 | 10 | 15 | 4.2 |
| XII | Position of throttle | Wide open | Wide open | Wide open | Wide open | Wide open | Wide open | ⅓ open |
| XIII | Position of reverse lever | 5 | Corner | 5 | Corner | Corner | 6 | Corner |
| XIV | Draft, inches of mercury | 1.0 | 1.1 | 0.8 | 0.8 | 0.8 | 0.5 | 0.3 |
| XV | Draft, inches of water | 13.1 | 14.9 | 10.8 | 10.8 | 10.8 | 6.7 | 4.07 |
| XVI | Character of smoke | Dark | Dark | Light | Dark | Light | Light | Clear |

Tests—Locomotive No. 66
Observations

| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|
| 8–22 | 8–22 | 8–22 | 8–22 | 8–22 | 8–26 | 8–26 | 8–26 | 8–26 |
| 3:30 | 3:45 | 4:30 | 4:40 | 5:00 | 12:00 | 12:30 | 12:40 | 1:10 |
| p.m. | p.m. | p.m. | p.m. | p.m. | m. | p.m. | p.m. | p.m. |
| E. | E. | E. | E. | E. | 20° | 20° | 60° | 60° |
| 7.84 | 7.84 | 5.71 | 5.71 | 5.71 | 8.50 | 8.37 | 8.70 | 8.70 |
| 63° | 63° | 63° | 63° | 63° | 70° | 68° | 70° | 70° |
| Clear | Cloudy | Cloudy | Cloudy | Cloudy | Clear | Clear | Clear | Clear |
| 12 | 9 | 5 | 5 | 5 | 3 | 3 | 3 | 3 |
| 616 | 457 | 229 | 229 | 229 | 150 | 150 | 150 | 150 |
| 55 | 23⅘ | 26⅕ | 32 | 15 | 27⅖ | 16 | 36 | 14⅖ |
| 6.5 | 15 | 13.5 | 11.3 | 24 | 13 | 22 | 10 | 25 |
| 14 | 7 | 10 | 7 | 7 | 4 | 8 | 4 | 8 |
| 5 | 9 | 6 | 9 | 12 | Corner | 12 | Corner | 12 |
| 1.1 | 1.1 | 0.8 | 0.8 | 1.2 | 1.2 | 1.1 | 0.8 | 1.1 |
| 14.9 | 14.9 | 10.8 | 10.8 | 16.3 | 16.3 | 14.9 | 10.8 | 14.9 |
| Light | Light | Light | Light | Light | Light | Light | Black | Light |

Tests—Locomotive No. 9
Observations

| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|
| 9–9 | 9–9 | 9–9 | 9–9 | 9–9 | 9–9 | 9–9 | 9–9 | 9–9 | 9–9 |
| 11:58 | 12:12 | 12:25 | 1:00 | 1:12 | 1:54 | 2:09 | 2:18 | 2:35 | 2:50 |
| a.m. | p.m. | p.m. | p.m. | p.m. | p.m. | p.m. | p.m. | p.m. | p.m. |
| 15° | 15° | 15° | 15° | 15° | 15° | 15° | 15° | 15° | 15° |
| 8.07 | 8.04 | 7.20 | 7.65 | 8:20 | 8.20 | 7.84 | 5.60 | 7.50 | 6.40 |
| 79° | 79° | 78° | 81° | 80° | 82° | 81° | 81° | 81° | 82° |
| Clear | Clear | Clear | Clear | Clear | Clear | Clear | Clear | Clear | Clear |
| 5 | 5 | 5 | 3 | 3 | 3 | Caboose | Caboose | Caboose | Caboose |
| 350 | 350 | 350 | 210 | 210 | 210 | | | | |
| 34⅘ | 25⅗ | 19 | 42 | 17⅗ | 31⅕ | ........ | ......... | 15 | 27⅕ |
| 10.5 | 14 | 19 | 7.6 | 21 | 11.6 | ......... | 4 app. | 24 | 13 |
| ½ open | Wide open | Wide open | ½ open | Wide open | ½ open | Wide open | Slightly open | Wide open | ½ open |
| 3 | 3 | 4 | Corner | 4 | 3 | 6 | Corner | 1 | Corner |
| 0.4 | 0.8 | 0.9 | 0.3 | 0.1 | 0.4 | 1.6 | 0.1 | 1.5 | 0.5 |
| 5.4 | 10.8 | 12.2 | 4.07 | 1.31 | 5.4 | 21.7 | 1.31 | 20.4 | 6.7 |
| Dark | Dark | Clear | Clear | Light | Clear | Light | Light | Light | Light |

no wind was encountered whose velocity exceeded ten miles per hour. Those winds which did prevail ranged from three to nine miles per hour.

**6. Data Observed and Tabulated.**—The general observations made, as based on the operating and weather conditions under which the tests were conducted with the two locomotives, are given in Tables VIII and IX.

It especially will be noted that the variety of speeds secured was fairly wide in scope and that the locomotives were worked over their entire range of capacities, as indicated by the tonnages hauled, reverse and throttle lever position, front end drafts, and train speeds. The results secured, therefore, should afford good indications of what might be looked for from locomotive sparks formed under average as well as heavy operating conditions.

The observed results of each test were carefully entered on prepared forms, typical examples of which, properly filled out for one test with each locomotive, are shown in Tables X and XI, respectively.

**7. Summary of Results Locomotive No. 66.**—After the data secured from all the tests made with both locomotives had been properly entered and extended in tabular form, as previously described and illustrated, it was grouped on the basis of train tonnages and temperature of sparks caught. Curves were then plotted to show graphically the relation between the amount of work performed by the locomotive, the quantity of sparks scattered, the distance the sparks traveled perpendicularly to the track, and the temperature at which the sparks struck the ground. These results for Monon locomotive No. 66 are presented in summary form in the following figures, each of which is described separately.

In all of the curves the circles show at what distance sparks were caught in the pans containing cotton fleece. It should be noted, however, that the curves were extended beyond the point at which some sparks were caught upon the fleece. This

## TABLE X.—TYPICAL OBSERVED, CALCULATED AND ESTIMATED SPARK DATA
### Test No. 12, Locomotive No. 66—Monon Tests

| Position of pans lined with fleece | Distance of pans from center of track, feet | Approximate distance of locomotive from pan when spark was released, feet | Weight of sparks caught in each pan, grams | Equivalent weight of sparks per 100 sq. ft. grams | Position of pans lined with paraffine | Condition and number of sparks caught | Approximate maximum temperature of hottest spark when landing in pan, deg. F. |
|---|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII | VIII |
| $A_1$ | 25 | 73 | .078 | 7.8 | $A_2$<br>$A_3$<br>$A_4$ | $M_2$–$S_4$<br>$M_2$–$S_8$<br>$M_2$–$S_7$ | 800<br>300<br>400 |
| $B_1$ | 45 | 131 | .28 | 28 | $B_2$<br>$B_3$<br>$B_4$ | $M_3$–$S_8$<br>$M_3$–$S_{12}$<br>$M_2$–$S_{11}$ | 900<br>1000<br>1000 |
| $C_1$ | 65 | 190 | .221 | 22.1 | $C_2$<br>$C_3$<br>$C_4$ | $S_4$<br>$M_1$–$S_{11}$<br>$M_3$–$S_2$ | 200<br>300<br>800 |
| $D_1$ | 85 | 248 | .086 | 8.6 | $D_2$<br>$D_3$<br>$D_4$ | F<br>F<br>$S_1$ | 200 |
| $E_1$ | 105 | 307 | .011 | 1.12 | $E_2$<br>$E_3$<br>$E_4$ | T<br>T<br>T | |
| $F_1$ | 125 | 365 | .015 | 1.58 | $F_2$<br>$F_3$<br>$F_4$ | F<br>F<br>F | |
| $G_1$ | 150 | 438 | .016 | 1.64 | $G_2$<br>$G_3$<br>$G_4$ | F<br>F<br>F | |

*Column III*.—Approximate distance of locomotive from pan when spark was released.—Values obtained by considering wind direction at time spark was caught as the direction of the hypothenuse of a right-angled triangle, whose base is the distance of the pan from the track and whose altitude the distance of the locomotive from the intersection of the base line with the track center line at the instant the spark is released. Thus by a simple trigonometrical calculation the length of the hypothenuse can be obtained.

*Column VII*.—Condition and number of sparks caught.—After the paraffine pans were collected, the surface of the hardened paraffine, was gently brushed with a fine hair brush. This light brushing removed all the dust and loose sparks which had not been warm enough, when they landed, to imbed themselves in the paraffine. Before the pans were brushed, they were graded as to quantity and character of sparks caught. The following designations were made:

M—evidence of paraffine around spark having melted.
S—spark stuck to paraffine, but no melting.
F—only faint trace of any sparks in pan, previous to light brushing.
T—larger quantity and sizes of sparks than F.
TH—large quantity and large size of sparks.

Numeral subscripts attached to letters signify the number of sparks that were melted in or merely stuck to the paraffine in each pan.

*Column VIII*.—Approximate maximum temperature of hottest spark caught when landing in pan.—This temperature was obtained by very carefully noting the disturbance to the paraffine around the sparks in question and comparing this, as well as the size of the spark, with the results secured by the laboratory tests described in Chapter VII, page 80. The temperature being known of the laboratory spark which caused the disturbance to the paraffine most closely approximating that of the field spark, it became possible to estimate the temperature of the sparks caught in the field.

## TABLE XI.—TYPICAL OBSERVED, CALCULATED AND ESTIMATED SPARK DATA

Test No. 17, Locomotive No. 9—Monon Tests

| Position of pans lined with fleece | Distance of pans from center of track, feet | Approximate distance of locomotive from pan when spark was released, feet | Weight of sparks caught in each pan, grams | Equivalent weight of sparks per 100 square feet, grams | Position of pans lined with paraffine | Condition and number of sparks caught | Approximate maximum temperature of hottest spark caught when landing in pan, deg. F. |
|---|---|---|---|---|---|---|---|
| I | II | III | IV | V | VI | VII | VIII |
| $A_1$ | 25 | 28 | .051 | 5.14 | $A_2$<br>$A_3$<br>$A_4$ | $S_1$<br>$S_3$<br>F | 200<br>200 |
| $B_1$ | 45 | 52 | .128 | 12.84 | $B_2$<br>$B_3$<br>$B_4$ | $S_4$<br>$S_3$<br>T | 200<br>400<br>200 |
| $C_1$ | 65 | 75 | .123 | 12.32 | $C_2$<br>$C_3$<br>$C_4$ | $S_2$<br>T*H*<br>$S_1$ | 200<br>200 |
| $D_1$ | 85 | 98 | .063 | 6.30 | $D_2$<br>$D_3$<br>$D_4$ | T<br>T<br>T | |
| $E_1$ | 105 | 121 | .049 | 4.9 | $E_2$<br>$E_3$<br>$E_4$ | $S_1$<br>T<br>F | |
| $F_1$ | 125 | 144 | .019 | 1.94 | $F_2$<br>$F_3$<br>$F_4$ | F<br>F<br>F | |
| $G_1$ | 150 | 173 | .02 | 2.00 | $G_2$<br>$G_3$<br>$G_4$ | F<br>F<br>F | |

### Explanation of Columns

*Column III.*—Approximate distance of locomotive from pan when spark was released.—Values obtained by considering wind direction at time spark was caught as the direction of the hypothenuse of a right-angled triangle, whose base is the distance of the pan from the track and whose altitude the distance of the locomotive from the intersection of the base line with the track center line at the instant the spark is released. Thus by a simple trigonometrical calculation the length of the hypothenuse can be obtained.

*Column VII.*—Condition and number of sparks caught.—After the paraffine pans were collected, the surface of the hardened paraffine was gently brushed with a fine hair brush. This light brushing removed all the dust and loose sparks which had not been warm enough, when they landed, to imbed themselves in the paraffine. Before the pans were brushed, they were graded as to quantity and character of sparks caught. The following designations were made:

M—evidence of paraffine around spark having melted.
S—spark stuck to paraffine, but no melting.
F—only faint trace of any sparks in pan, previous to light brushing.
T—larger quantity and sizes of sparks than F.
TH—large quantity and large size of sparks.
Numeral subscripts attached to letters signify the number of sparks that were melted in or merely stuck to the paraffine in each pan.

*Column VIII.*—Approximate maximum temperature of hottest spark caught when landing in pan.—This temperature was obtained by very carefully noting the disturbance to the paraffine around the sparks in question and comparing this, as well as the size of the spark, with the results secured by the laboratory tests described in Chapter VII, page 80. The temperature being known of the laboratory spark which caused the disturbance to the paraffine most closely approximating that of the field spark, it became possible to estimate the temperature of the sparks caught in the field.

extension indicates that a faint trace of spark material was found upon the paraffine lined pans which however was too light to weigh. The ends of the curves, therefore, represent the extreme distances from the center of the track at which any evidence of spark material, however slight, were obtained during each of the tests.

Figure 67 shows the results obtained with locomotive No. 66 operating under full tonnage. Test No. 3 was made at 9 miles per hour under full throttle and with reverse lever in the corner. The wind velocity was 4.9 miles per hour and was blowing almost directly across the track. Test No. 7 was made at 6.5 miles per hour with approximately a full throttle and reverse lever in the fifth notch. The wind velocity was 7.8 miles per hour and was blowing almost directly across the track.

The curves shown in Figure 68 were plotted by using the data obtained when operating the locomotive under three-fourths tonnage. Test No. 4 was made at 16 miles per hour with reverse lever in the sixth notch and the throttle lever in the tenth notch. The wind velocity was 6 miles per hour. The conditions for test No. 5 were approximately the same as for test No. 4. Test No. 6 was made at approximately 8 miles per hour, the other conditions being about the same as for tests No. 4 and 5.

The curves in Figure 69 give the results obtained with locomotive No. 66 operating under a 150 ton load. Test No. 12 was made at 13 miles per hour, with the reverse lever in corner and the throttle lever in the fourth notch. The wind velocity was 8½ miles per hour. Test No. 13 was made at 22 miles per hour, with the reverse lever in the twelfth notch and the throttle lever in the eighth notch. Test No. 14 was made at 10 miles per hour, with the reverse lever in the corner and the throttle lever in the fourth notch. Test No. 15 was made at 25 miles per hour, with the reverse lever in the twelfth notch and the throttle lever in the eighth notch.

Although a rather wide speed variation was used in this series, the results are not greatly different.

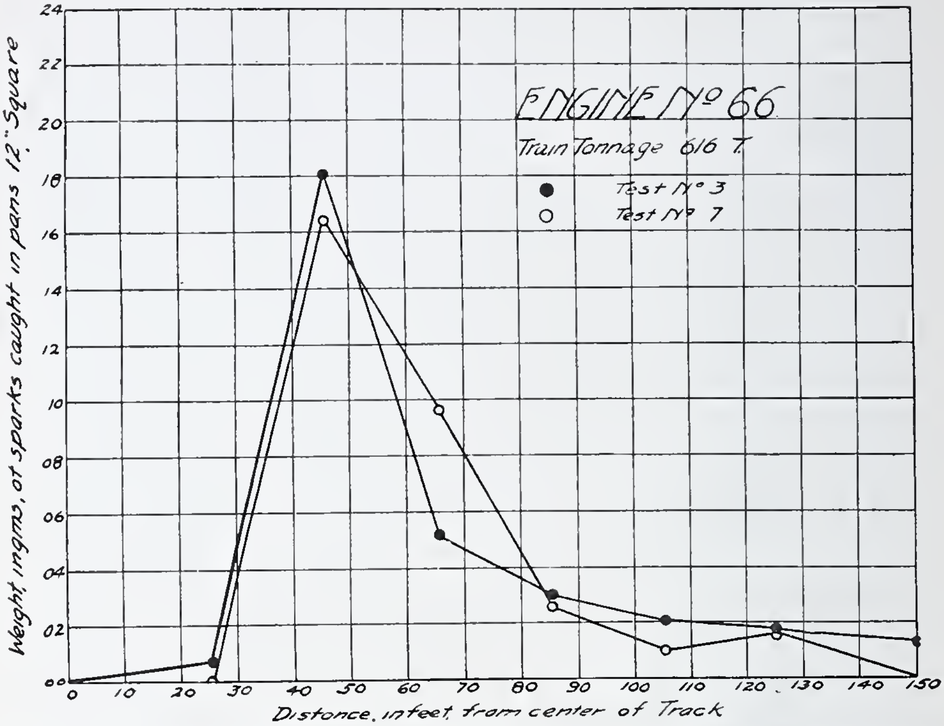

FIG. 67.—Relation between weight of sparks caught and distance from center of track. Monon Tests Nos. 3 and 7.

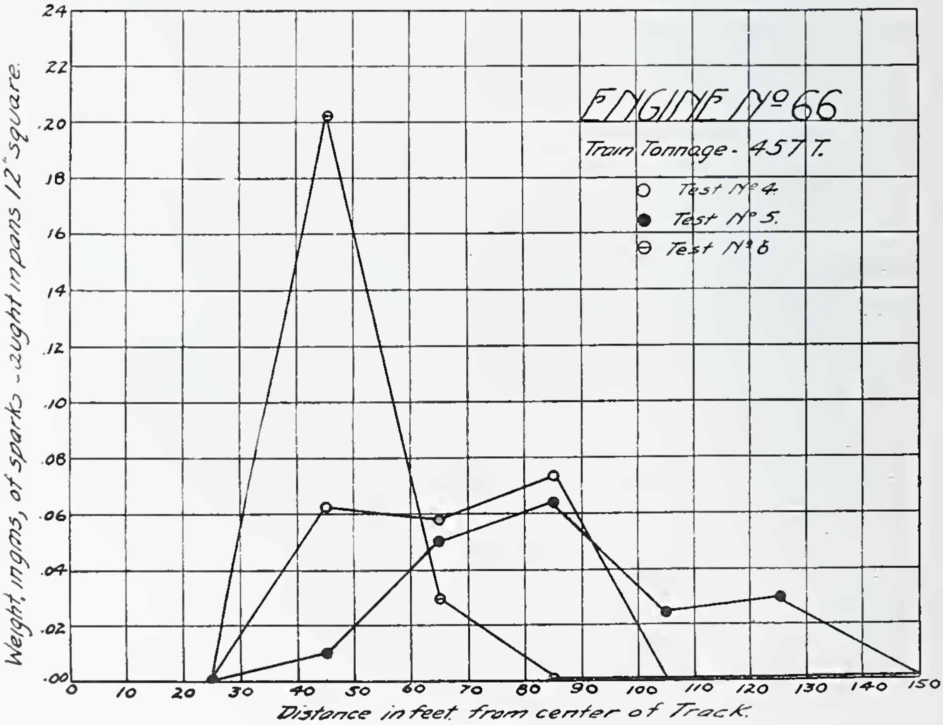

FIG. 68.—Relation of weight of sparks caught and distance from center of track. Monon Tests Nos. 4, 5 and 6.

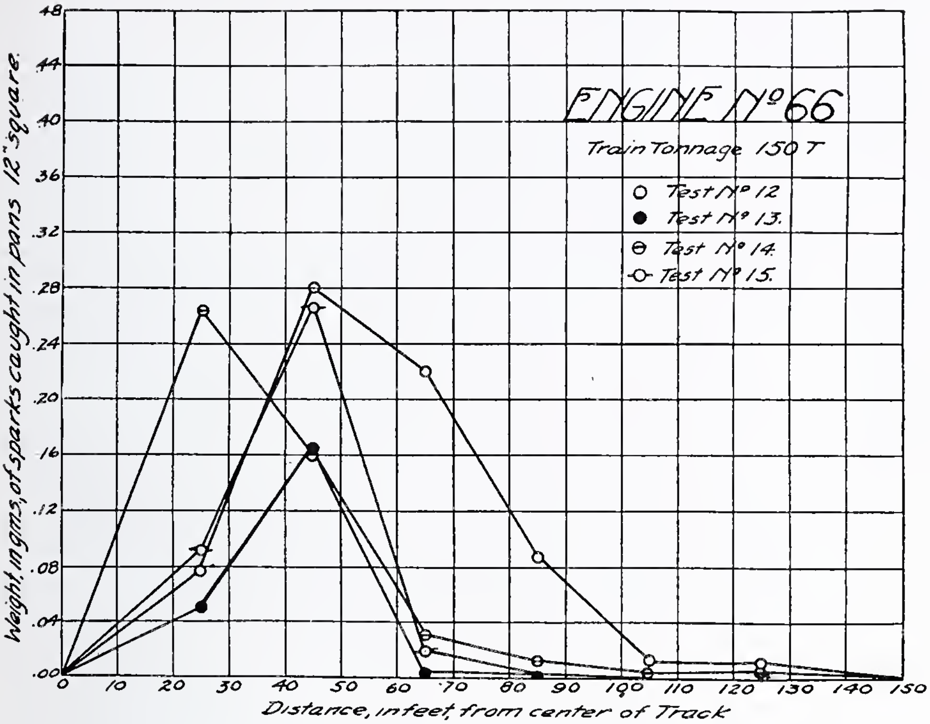

FIG. 69.—Relation between weight of sparks caught and distance from center of track. Monon Tests Nos. 12, 13, 14 and 15.

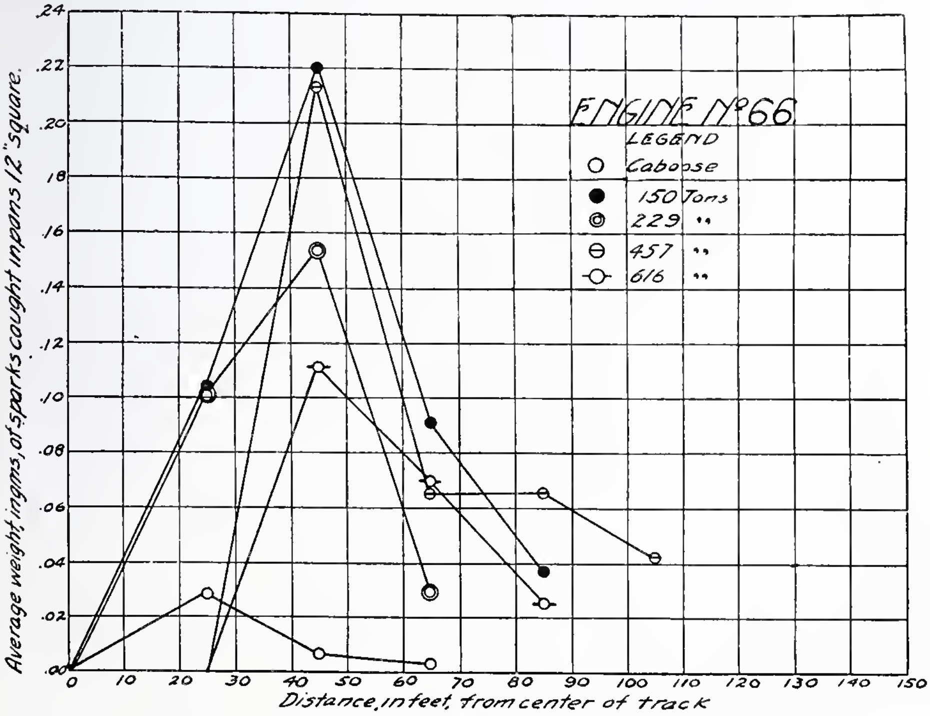

FIG. 70.—Relation between average weight of sparks caught and distance from center of track, different tonnage trains. Monon Tests.

(a) Average Results.—To summarize the results, the curves shown in Figure 70 were plotted in the following manner: The average weight of sparks caught in each pan for all the tests, when only the caboose was attached to the locomotive, was found. The value thus obtained was plotted as shown. In like manner the average weight was computed for each pan position for the several tonnages. These curves therefore show the results to be expected under all speed conditions and for all ways of operating the locomotive under each tonnage.

(b) Discussion of the Curves.—Several significant facts are to be recognized regarding the curves as presented for the individual test results, as well as for the averaged results. The first one concerns the general character of the curves. Regardless of tonnage, wind velocity, train velocity, or the manner in which the locomotive was operated, the characteristics of the spark distribution curves are very similar. The second point is, that in almost every case the maximum weight of sparks was caught in either the A or B series of pans, which were 25 or 45 feet from the center of the track. The only exceptions to this were in the case of tests No. 4 and 5.

The third significant point shown by the curves is that no spark material trace fell beyond 150 feet from the center of the track. Out of all the tests made, there was only one in which a sufficient quantity of sparks was caught at 150 feet from the center of the track which actually could be weighed.

The fourth significant point is that the quantity of sparks scattered to the right and left of the locomotive was not very greatly affected by an increase in the load of the locomotive. As far as it is possible to make such a comparison, there seems to be no relation between the weight of sparks and the different test conditions. It is evident, however, as the tonnage was increased, that the range over which the sparks were spread increased. For tests with the caboose only, the total spread of the sparks was 85 feet from the center of the track, whereas for tests with 616 tons the spread was 150 feet.

The fifth important thing to be noted is that, of the entire weight of sparks caught, 71% of the total fell within 45 feet of the center of the track and 85% were caught within 65 feet of the center of the track.

It is obviously difficult to make a comparison of individual tests as to weight and distance because of many varying factors. But the general tendency, both of individual tests and of averaged results is marked, and the five specific indications stated above are quite distinct and definite.

**8. Summary of Locomotive No. 9.**—Locomotive No. 9 was tested in the same manner as Locomotive No. 66, and the curves shown in Figures 71 and 72 were plotted in like manner.

These curves give an interesting comparison as to the effect of the speed. Test No. 22 was made at 4.2 miles per hour, and a very small quantity of sparks was caught. None were caught farther out than 85 feet. Test No. 25 at 19 miles per hour gave a much larger quantity of sparks and also threw them farther, some being caught at 125 feet and a trace was found at 150 feet.

(a) Average Results.—The averaged results for locomotive No. 9 are plotted in Figure 72. These curves are also quite consistent in their tendencies for their general characteristics are about the same. It will be noted that no sparks were caught farther than 65 feet from the track when the caboose alone was attached. With a tonnage of 210, 350, and 570 respectively, sparks were caught as far out as 125 feet, whereas with a full tonnage of 630 a comparatively large amount was caught at 150 feet, but at the next station no trace was obtained.

(b) Discussion of the Curves.—It is interesting to note that the curves shown in Figures 71 and 72 for locomotive No. 9 show the same general tendency as did those for locomotive No. 66. That is, first, regardless of train or wind velocity, the method of operating the train, or the tonnage hauled, the maximum weight of sparks was caught within 50 feet of the track. Second, there was no indication that any considerable amount of sparks fell beyond 150 feet from the center of the track. Third, that the

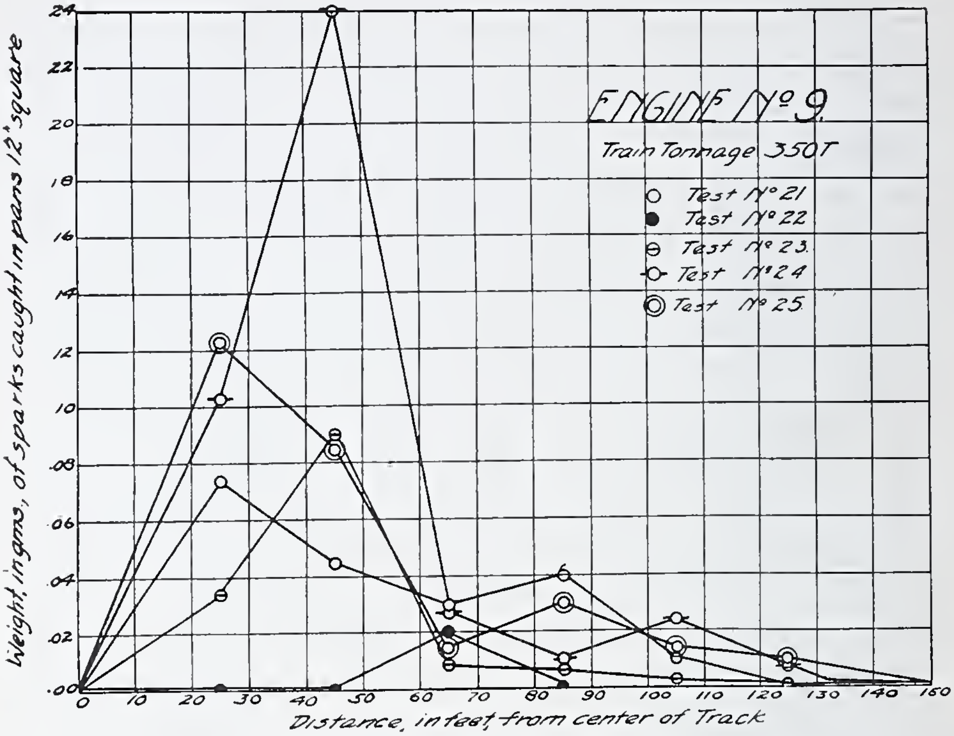

Fig. 71.—Relation between weight of sparks caught and distance from center of track. Monon Tests Nos. 21, 22, 23, 24 and 25.

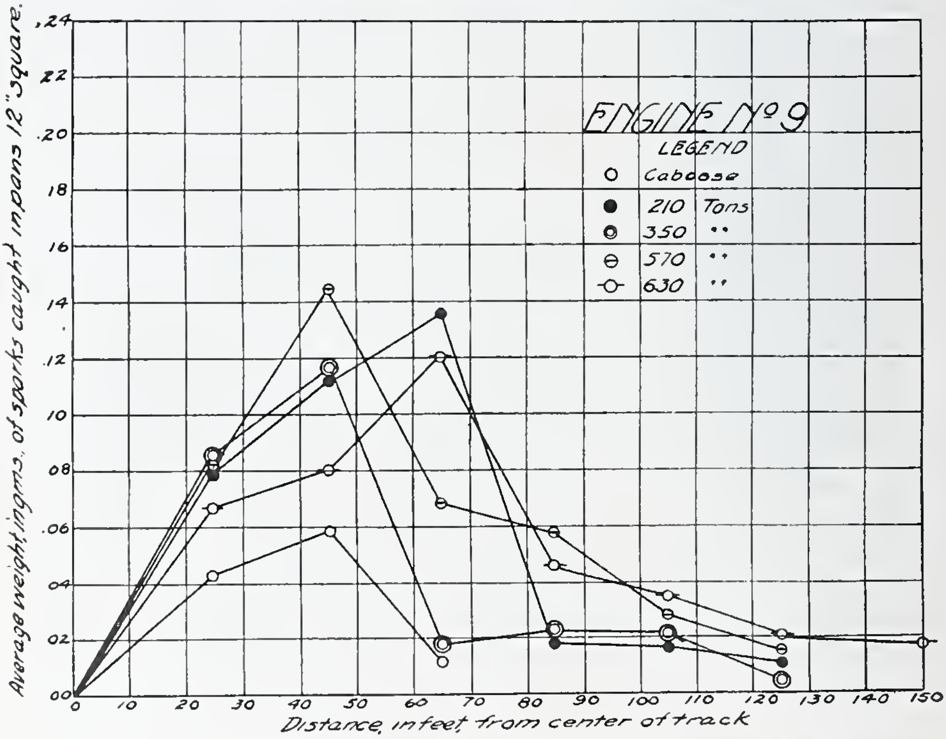

Fig. 72.—Relation between average weight of sparks caught and distance from center of track, different tonnage trains. Monon Tests.

total quantity scattered sidewise was apparently not greatly affected by an increase in tonnage. Fourth, as the tonnage increased the distance perpendicular to the track over which the sparks were caught was increased. This was somewhat more pronounced with locomotive No. 9 than with locomotive No. 66. But notwithstanding this, 62% by weight of all sparks caught from locomotive No. 9 fell within 50 feet of the center of the track, while 81% fell within 65 feet of the center, the difference being only 4% in the latter value for the two locomotives.

**9. Spark Temperatures and Fire Danger Indications.**—The paraffine lined pans used during these tests were carefully graded as to the quantity and condition of sparks caught. The surface of the paraffine was lightly brushed in order to remove any sparks that were not actually sticking to the surface. The sparks remaining were classified as "melted," comprising all those that showed signs of having melted the paraffine. All others were designated as "stuck." The total number of sparks from both locomotives, for all tests, that were found to have been warm enough to stick to or melt into the paraffine was 613; 83 % of these were caught in the A and B series of pans, or within 45 feet of the track, and 96% (591 sparks) in the A, B, and C series, or within 65 feet from the center of the track.

In Figure 73 the total number of sparks caught in each pan for each locomotive was plotted against the distance from the center of the track. The curves show that beyond 85 feet from the center of the track no sparks fell that were hot enough to stick to the paraffine.

Tables XII and XIII have been prepared from the results of the thirty-two tests to show the relation between estimated temperature of hottest sparks caught during each test and the distance from the center of the track at which these sparks struck the ground. The last or summary column indicates the hottest spark for all of the tests of each locomotive which landed in each row of pans, A, B, C, etc., respectively. The latter data has been combined and is presented graphically in Figure 74. It is evident from the information presented in the tables that there is not enough data available to trace any close relation between spark temperatures and locomotive operating conditions. Figure 74, however, shows that there is a relation between the maximum temperature of sparks and the distances which they travel after they leave the locomotive. The sparks which alight close to the track are hotter than those falling at the more remote distances. And of course this is quite logical.

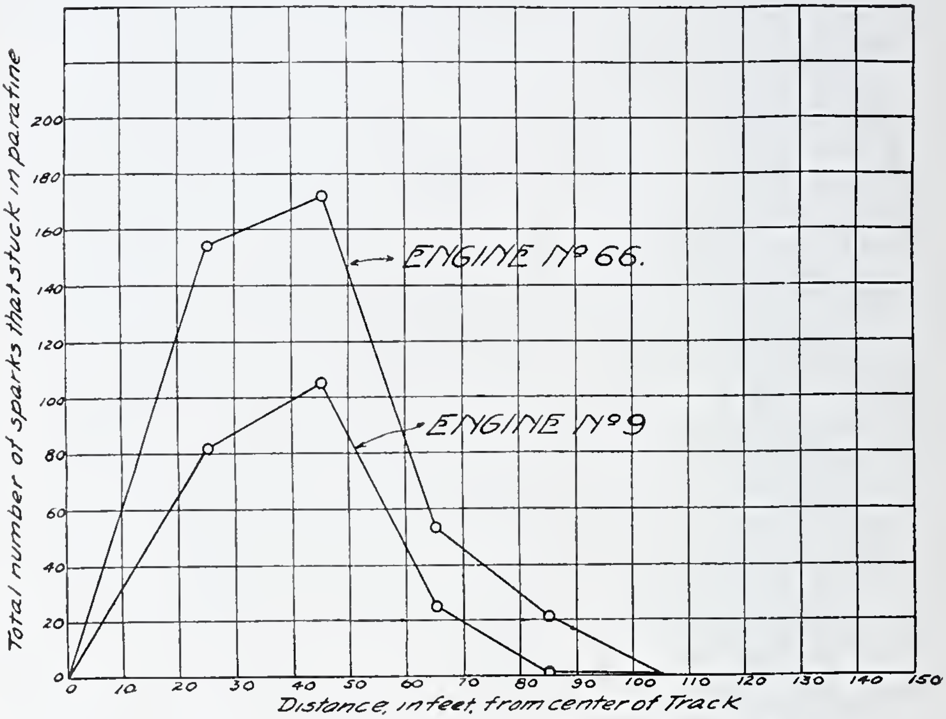

Fig. 73.—Relation between total number of sparks which stuck to paraffine and distance from center of track, all Monon Tests.

The thing of greatest importance, however, with reference to the temperatures at which sparks land upon the ground as revealed by these particular tests is that only in one case was a spark caught whose temperature was high enough, i.e., 1200° to permit of classifying it as dangerous from a fire-starting point of view. This spark fell twenty-five feet from the center of the track. It was caught in Test No. 14 with locomotive No.

66, running, as will be noted by referring to Table VIII, at 10 miles per hour, with a train load of 150 tons, or about 25% of the maximum, a draft in front end of 0.8 inches on the mercury gauge, the reverse lever in the corner, and a wind of 8.7 miles per hour blowing at 60° to the track. By referring to Table VII it will be noted on page (85), that only sparks ¼ inch and larger at a temperature of 1200° to 1400° ignite dry grass or similar combustible material. Sparks at this temperature actually glow. Several were caught whose temperature, when they landed, was around 1000°. Their sizes were from 3/16 to ¼ of

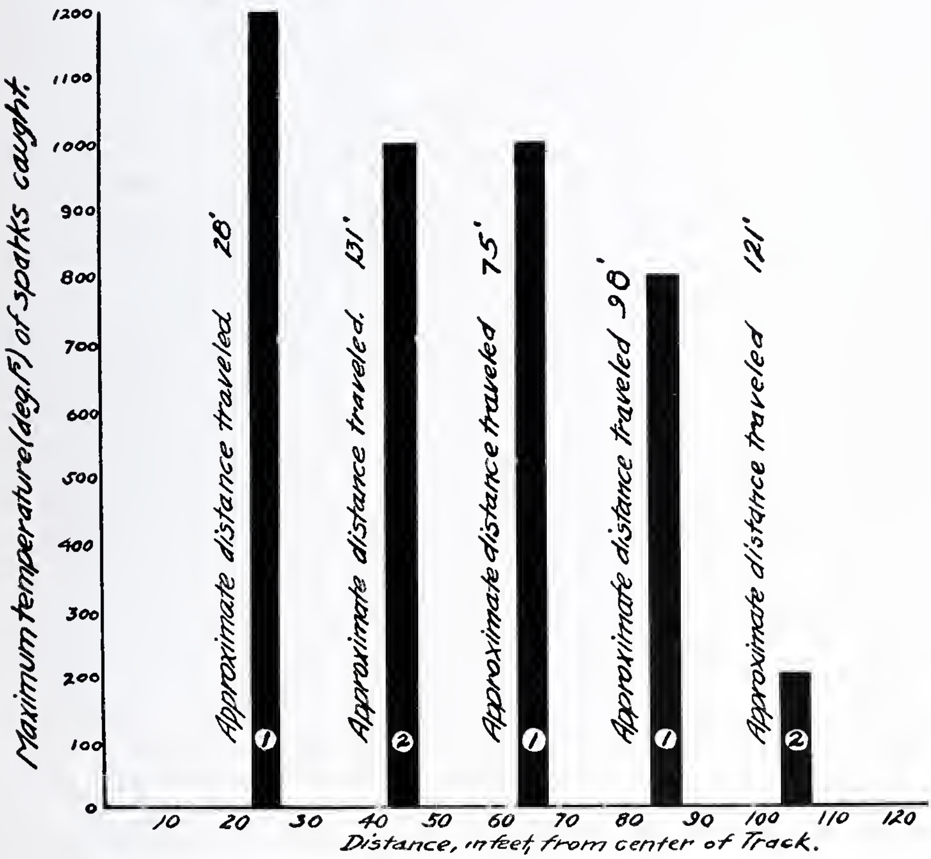

FIG. 74.—Maximum temperature of sparks caught at different distances from center of track. Monon Tests.[1]

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[1] The figure in the circle donates the TOTAL number of sparks caught at the temperature plotted. For example: only one spark of the 613 registered 1200°.

### TABLE XII.—SPARK TEMPERATURE RESULTS LOCOMOTIVE NO. 66—MONON TESTS

| Row of pans | Distance of row from center of track, feet | Maximum temperature in degrees Fahrenheit of sparks caught in each row of pans in each test | | | | | | | | | | | | | | | Maximum spark temperature found |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| A | 25 | 200 | 800 | 500 | 300 | 200 | ... | ... | 200 | 700 | .... | 200 | 800 | 800 | 1200 | 800 | 1200 |
| B | 45 | 700 | ... | 800 | 800 | 200 | 700 | 200 | 700 | 200 | .... | 200 | 1000 | 900 | 700 | 900 | 1000 |
| C | 65 | ... | 200 | 200 | 1000 | 400 | 200 | ... | 400 | ... | .... | ... | 800 | ... | 200 | 200 | 1000 |
| D | 85 | ... | ... | 700 | 800 | 200 | ... | ... | ... | ... | .... | ... | 200 | ... | ... | ... | 800 |
| E | 105 | | | | | | | | | | | | | | | | |
| F | 125 | | | | | | | | | | | | | | | | |
| G | 150 | | | | | | | | | | | | | | | | |

### TABLE XIII.—SPARK TEMPERATURE RESULTS LOCOMOTIVE NO. 9—MONON TESTS

| Row of pans | Distance of row from center of track, feet | Maximum temperature in degrees Fahrenheit of sparks caught in each row of pans in each test | | | | | | | | | | | | | | | | | Maximum spark temperature found |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | |
| A | 25 | 500 | 200 | 200 | 200 | 200 | 200 | ... | 200 | 200 | 300 | 800 | 700 | ... | 200 | ... | 200 | ... | 800 |
| B | 45 | 700 | 400 | 400 | 200 | 200 | 800 | ... | ... | 500 | 300 | 800 | ... | 200 | 400 | ... | ... | ... | 800 |
| C | 65 | 800 | 200 | 200 | ... | ... | 300 | ... | ... | 300 | 200 | 300 | ... | 200 | ... | ... | ... | ... | 800 |
| D | 85 | | | | | | | | | | | | | | | | | | |
| E | 105 | 200 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 200 |
| F | 125 | | | | | | | | | | | | | | | | | | |
| G | 150 | | | | | | | | | | | | | | | | | | |

an inch and they all fell within the 65-foot zone. Only when sparks of this temperature are well over ¼ inch in size would they be dangerous. As long as the temperature of sparks does not exceed 1200° and their size is kept below ¼ inch, all of which these tests reveal as being entirely possible, the danger of fire from sparks is practically reduced to zero.

**10. The Influence of the Wind on Spark Distribution.**—One of the purposes of the Monon tests was to determine, if possible, to what extent the distribution of locomotive sparks and the possibility of their starting fires was influenced by the velocity of the wind. To this end, data was obtained for a variation of wind rates within the limits of three and nine miles per hour. The data was then arranged according to wind velocity and tonnage hauled. From this data no satisfactory fixed law as to the wind influence could be developed.

Suffice it to say in general however, that, as the velocity of the wind increases, everything else remaining constant, the distance a spark will travel before falling to the ground will also increase. There is no evidence to show that there is any absolute ratio between the distance a spark may travel and the velocity of the wind prevailing at the time the spark leaves the stack. In fact, there is evidence which indicates that there is no such simple direct relation between the two factors involved. From a study of the data the deduction may be drawn that, as the velocity of the wind increases, there is a probability that the distance traveled by a spark will be greater, but it does not follow that because the wind is blowing at 10 miles per hour the sparks will be carried twice as far as when the wind is blowing 5 miles per hour.[1]

## II. THE LAKE ERIE & WESTERN RAILROAD TESTS

The purpose of these tests was to secure additional data concerning the effect of wind velocities and directions on spark distribution. They are therefore supplementary to the Monon Tests just described.

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[1] For a theoretical approach to this phase of the spark problem, the reader is referred to Dr. W. F. M. Goss's treatise, Locomotive Sparks, Chapter VII, pp. 129–144.

**11. Test Preparations.**—The territory selected for these tests was on the Lake Erie & Western Railroad about one mile west of Lafayette, Indiana, near the summit of a steep grade. The ground which was staked out to take the pans was to the north of the track. The gradient of the line, which was straight through the test territory, averaged .86%. These track conditions were selected largely with the object in view of making observations while the locomotives were working hard passing the plotted ground.

The ground over which the pans were distributed was staked out precisely as was done in the Monon Tests, shown in Figure 65. The pans used were also similar to those of the Monon Tests, lined with paraffine and cotton fleece respectively. The paraffined pans were located at one perpendicular row of stations and the fleece-lined pans at the three remaining rows. The balance of the apparatus used was identical with that employed in the Monon Tests, except that no locomotive readings other than speed and smoke conditions were taken.

The test procedure was also identical with that of the Monon Tests.

**12. Data Observed and Tabulated.**—Fourteen tests were made under varying wind conditions, as shown in Table XIV. Of these, seven were made with long freight trains equipped with a lead locomotive and a pusher, three with lighter freight trains hauled only by a lead locomotive, and four with passenger trains hauled by a single lead locomotive. Thus the sparks which fell in the first seven tests came from two locomotives. The test results were therefore separated into three groups, according to the number of locomotives hauling the trains, and the character of the trains, as follows:

| | |
|---|---|
| Group 1. | Freight trains with lead and pusher locomotive. |
| Group 2. | Freight trains with lead locomotive only. |
| Group 3. | Passenger trains with lead locomotive only. |

These groups were further subdivided into tests taking place during equivalent south wind velocities of from 0 to 6 miles per hour, 6 to 10 miles per hour, 10 to 20 miles per hour, and 20 to 30 miles per hour. By equivalent south wind velocities is meant the perpendicular component to the track of any wind blowing across the track from the south. The entire test results grouped on this basis will be found in Table XV.

TABLE XIV.—ORIGINAL DATA, LAKE ERIE AND WESTERN RAILROAD TESTS

| Test No. | Eng. No. | Pusher No. | No. of Cars | Cond of Smoke | Speed of Train | Vel of Wind | Dir of Wind | Time of Day | Temp of Air | No. of Sparks Sticking in Paraffin |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6426 | | 6 Pass. | Light | 20 MpH | 6.5 MpH | S.W.-45° | 1:40 P.M. | 70° F. | 2 in A |
| 2 | 6049 | 6785 | 65 | Black | 6 " | 9.1 " | S. -90° | 2:30 P.M. | 70° " | 7 " A<br>2 " B<br>1 " C |
| 3 | 6429 | | 8 Pass. | Light | 26.2 " | 13.6 " | S.W 45° | 2:00 P.M. | 65° " | |
| 4 | 6429 | | 7 Pass. | Medium | " | 5 " | S 90° | 1:50 P.M. | 75° " | |
| 5 | 6038 | 6670 | 56 | Light | 14.5 " | 5 " | S. 90° | 2:00 P.M. | 75° " | 1 " C<br>1 " D |
| 6 | 6051 | 7306 | 60 | Light | 17.7 " | 3 " | S. 90° | 9:15 A.M. | 70° " | |
| 7 | 5351 | | 16 | Medium | 14 " | 4 " | S. 90° | 9:50 A.M. | 70° " | |
| 8 | 5538 | 5513 | 65 | | 12.5 " | 5.5 " | S. 90° | 10:00 AM. | 70° " | |
| 9 | 6052 | 7306 | 66 | | 16.5 " | 7 " | S.W. 30° | 2:40 P.M. | 75° " | |
| 10 | 5527 | | 29 | Medium | 15.8 " | 11 " | S 90° | 6:30 P.M. | 70° " | |
| 11 | 6050 | 7306 | 55 | Medium | 14.25 " | 30 " | S.W. 30° | 1:30 P.M. | 70° " | 2 " A<br>1 " B<br>1 " D |
| 12 | 6051 | 7306 | 50 | | 17 " | 11.8 " | S. 90° | 8:30 A.M. | 70° " | |
| 13 | 5346 | | 10 | | 10.9 " | 20 " | S. 90° | 9:30 A.M. | 70° " | |
| 14 | 6435 | | 7 Pass. | Black | 30 " | 19 " | S.W. 45° | 1:50 P.M. | 70° " | 1 " D |

Figures 75 to 84 inclusive present the spark data observed and calculated for each test, together with the averages for each major group of tests. In these graphical illustrations the average weights of sparks in grams per pan of one square foot is plotted against the distance in feet at which the pan was located from the center of the track.

**13. Summary of Results.**—An inspection of the tabulated data, together with the graphical illustrations, confirms the fact already noted in the Monon Tests, namely, that most of the sparks caught fell on the first two sets of pans, i.e., the 25 and 45 feet rows running parallel to the track. This amount in these particular tests equaled 79%. The amount which fell within the 85-foot zone equaled 89%.

TABLE XV.—SUMMARY OF DATA, LAKE ERIE AND WESTERN RAILROAD TESTS

| Classification | | | Test No. | Equiv Wind Vel. | Wt. in gms., of sparks caught in pans 12" square | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 25 ft. | 45 ft. | 65 ft. | 85 ft. | 105 ft. | 125 ft. | 150 ft. |
| | | | | | A | B | C | D | E | F | G |
| Group # 1 One Engine - One Pusher | Equiv. So. Wind Vels. in M.p.H. from | 0 to 6 | 6 | 3 M.pH | | .009 | | | | | |
| | | | 9 | 8.5 | .011 | .009 | | | | | |
| | | | 5 | 5 | .025 | .011 | .004 | | | | |
| | | | 8 | 5.5 | .061 | .067 | .025 | .002 | | | |
| | | 6 to 10 | 2 | 9.1 | .053 | .044 | .013 | .018 | .002 | | |
| | | 10 to 20 | 12 | 11.8 | | .006 | | | .005 | .004 | Trace |
| | | | 11 | 14.4 | .040 | .033 | .018 | .004 | .002 | | |
| | | | Total | | .190 | .179 | .060 | .024 | .009 | .004 | |
| | | | Average | | .027 | .026 | .009 | .003 | .001 | .0006 | |
| Group # 2 One Engine | Equiv. So. Wind Vels. in M.p.H. from | 0 to 6 | 7 | 4 M.pH | .119 | .018 | | | | | |
| | | 10 to 20 | 10 | 11 | | | | .001 | .004 | | |
| | | | 13 | 17.3 | | .001 | .010 | .027 | .003 | | |
| | | | Total | | .119 | .019 | .010 | .028 | .007 | | |
| | | | Average | | .039 | .007 | .003 | .009 | .002 | | |
| Group # 3 Passenger | Equiv. So. Wind Vels. in M.p.H from | 0 to 6 | 1 | 4.5 | .004 | .012 | | | | | |
| | | | 4 | 5 | | | | | | | |
| | | 6 to 10 | 3 | 9.6 | | | | | | | |
| | | 10 to 20 | 14 | 13.3 | .070 | .009 | .003 | Trace | | .017 | |
| | | | Total | | .074 | .021 | .003 | | | .017 | |
| | | | Average | | .018 | .005 | .001 | | | .004 | |
| | | | Grand Total | | .383 | .227 | .073 | .052 | .016 | .021 | |

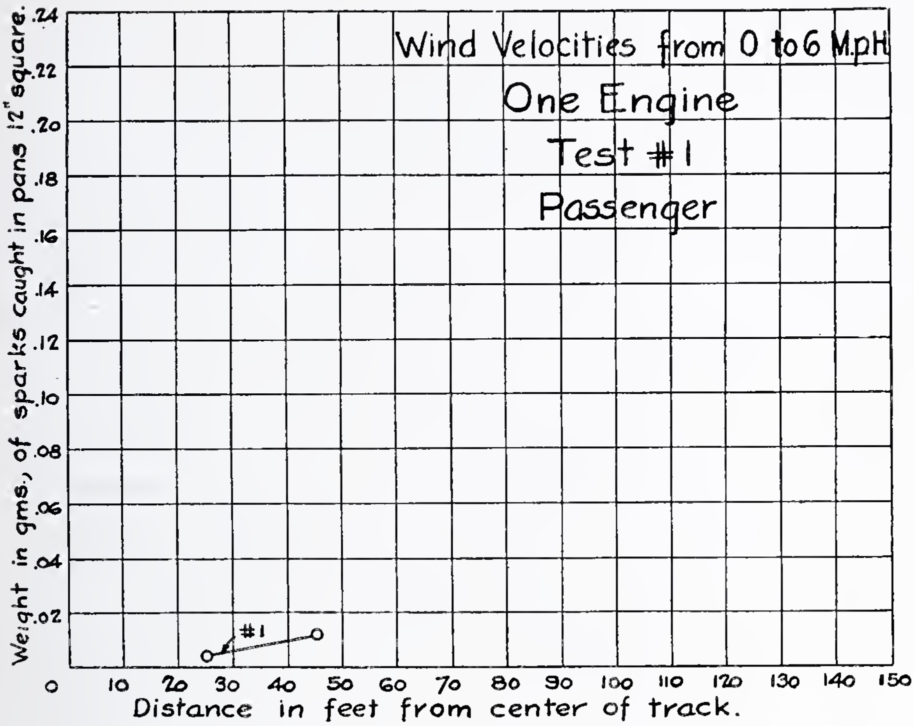


FIG. 75.—Wt. sparks caught per pan at different distances from center track at wind velocities from 0 to 6 m.p.h.

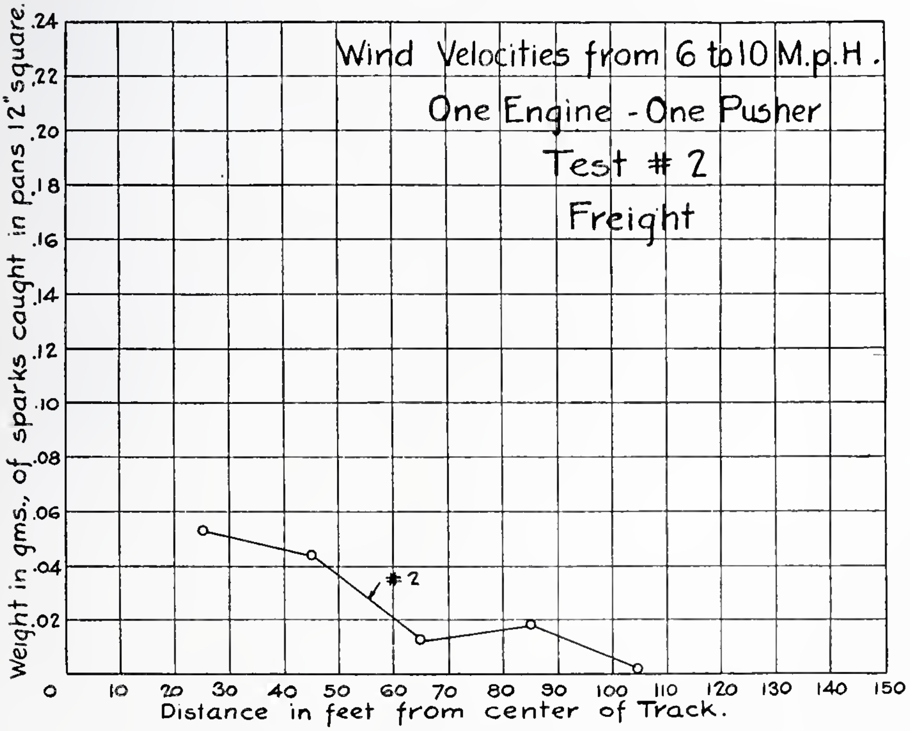


FIG. 76.—Wt. sparks caught per pan at different distances from center of track at wind velocities from 6 to 10 m.p.h.

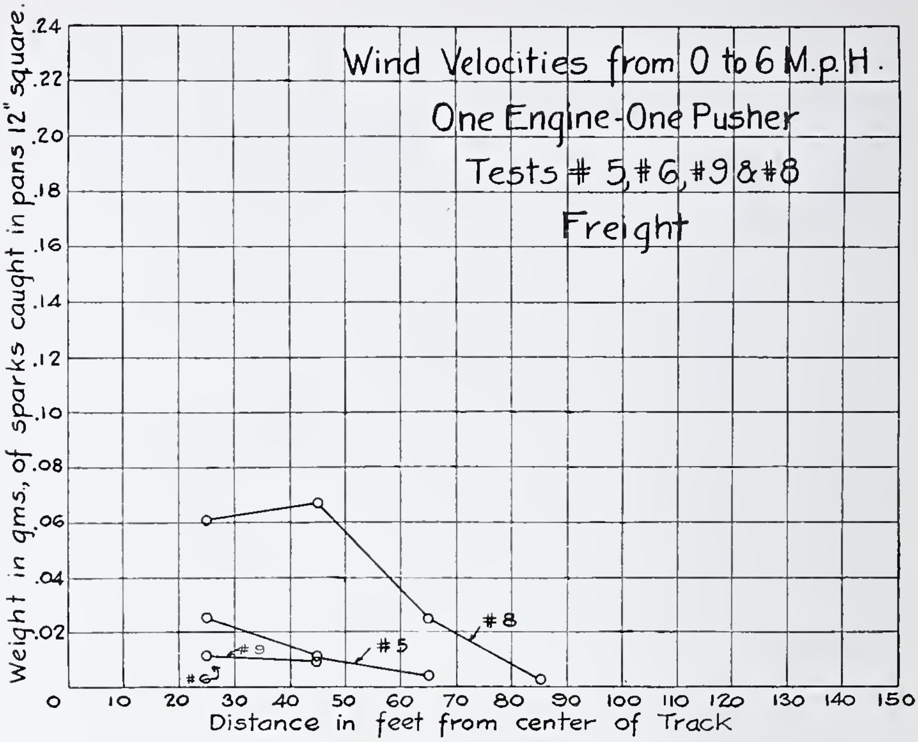


Fig. 77.—Wt. sparks caught per pan at different distances from center of track at wind velocities from 0 to 6 m.p.h.

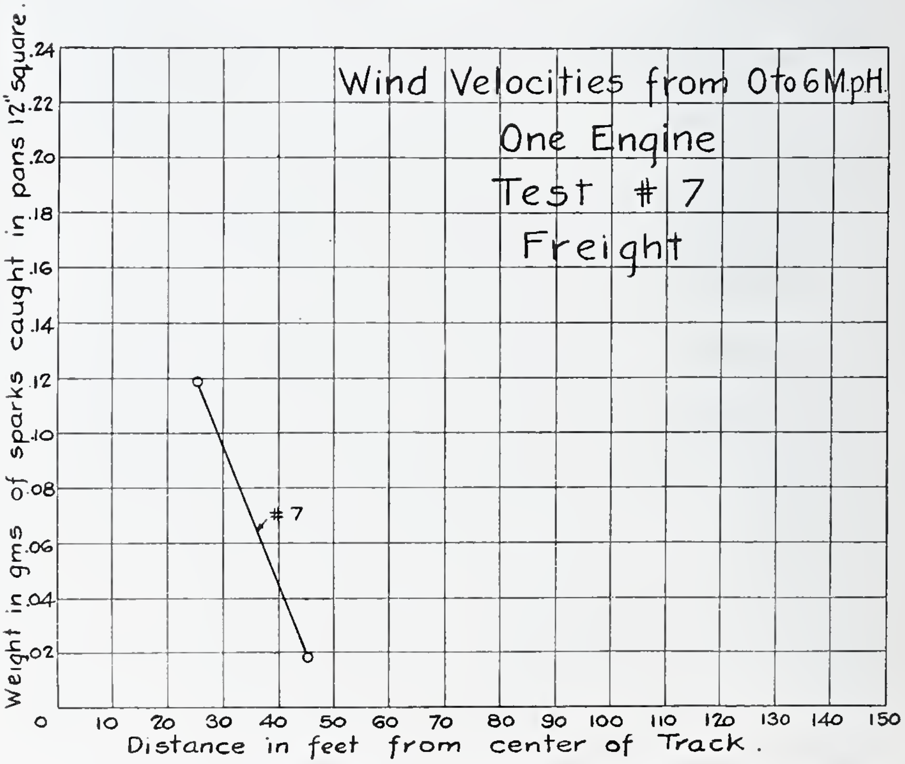


Fig. 78.—Wt. sparks caught per pan at different distances from center of track at wind velocities from 0 to 6 m.p.h.

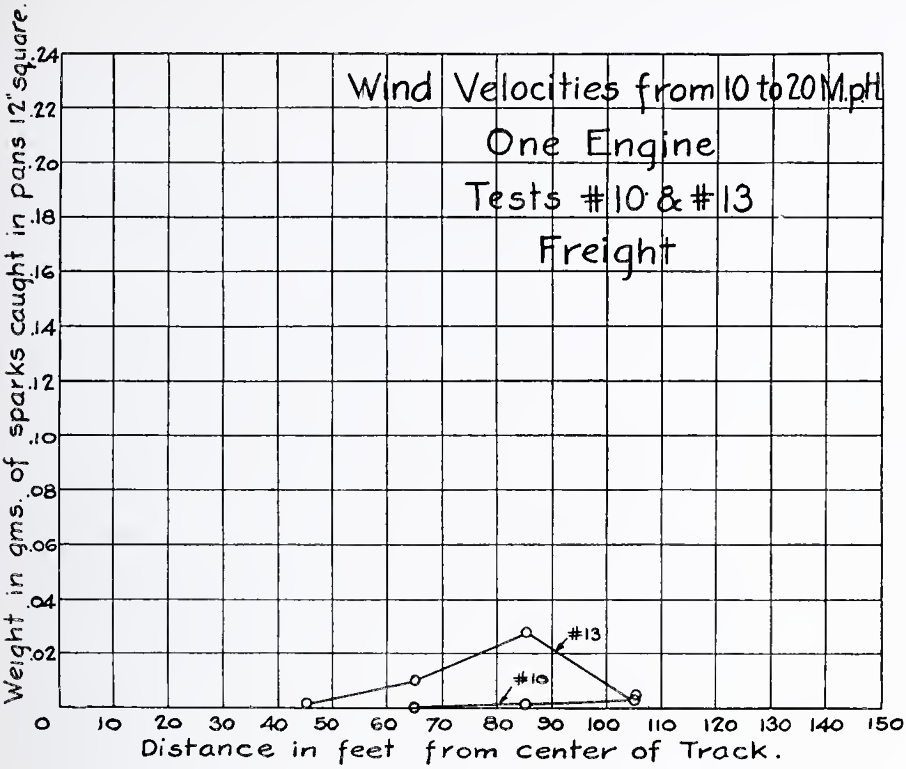


FIG. 79.—Wt. sparks caught per pan at different distances from center of track with wind velocities from 10 to 20 m.p.h.

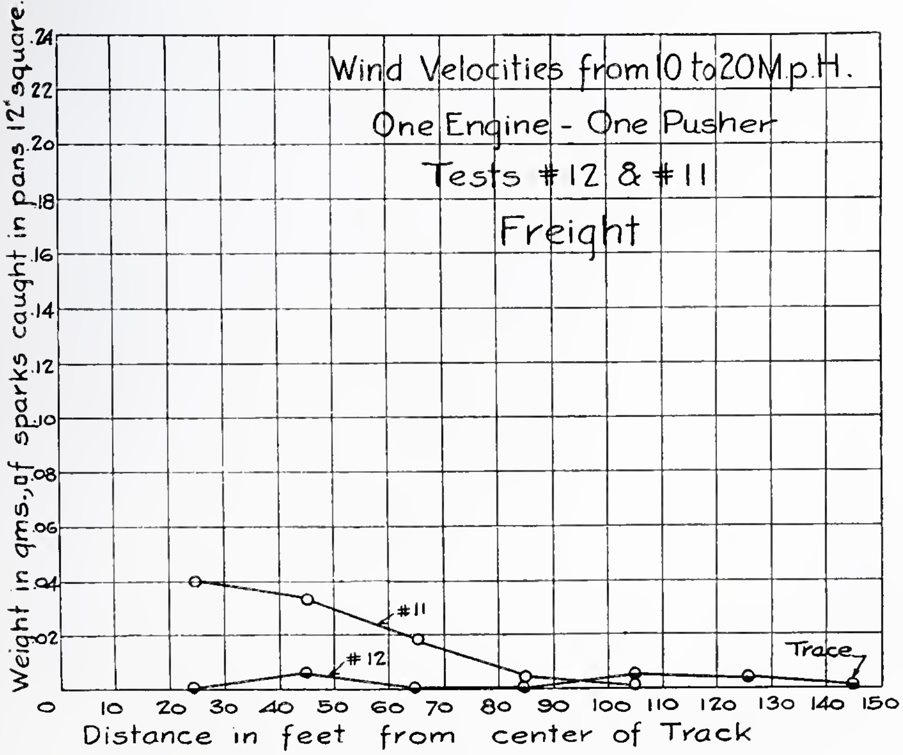


FIG. 80.—Wt. sparks caught per pan at different distances from center of track with wind velocities from 10 to 20 m.p.h.

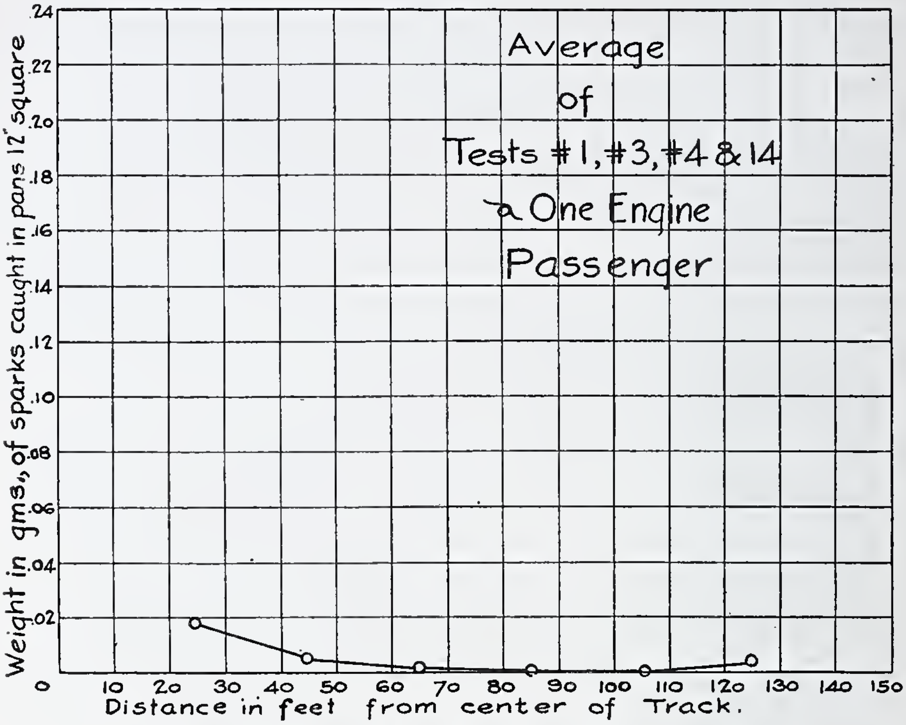


FIG. 81.—Wt. sparks caught per pan at different distances from center of track with wind velocities from 10 to 20 m.p.h.

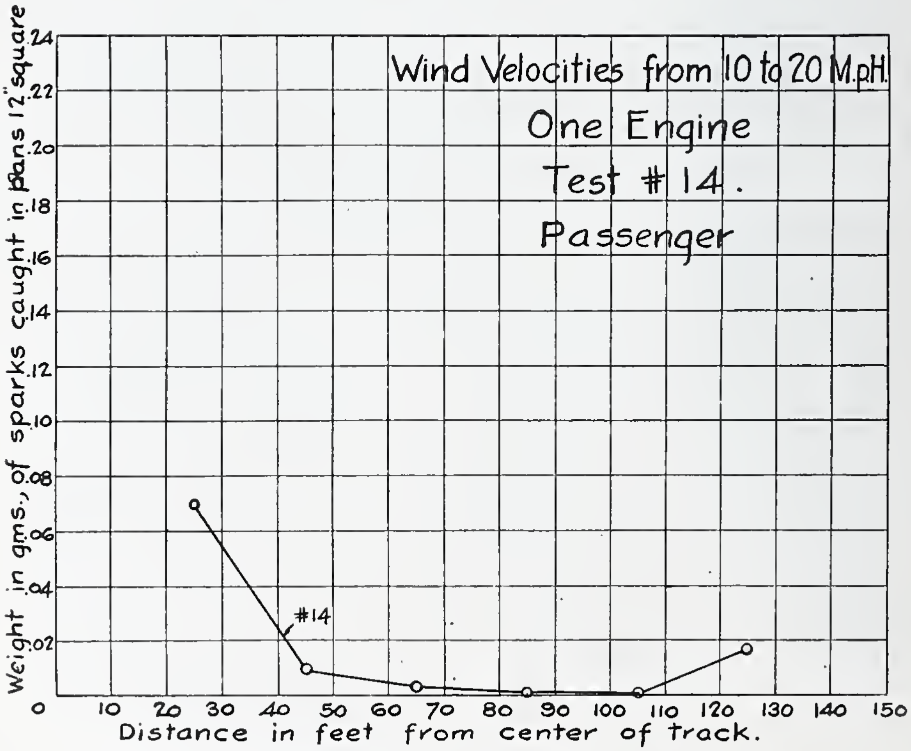


FIG. 82.—Average results of one locomotive in passenger service.

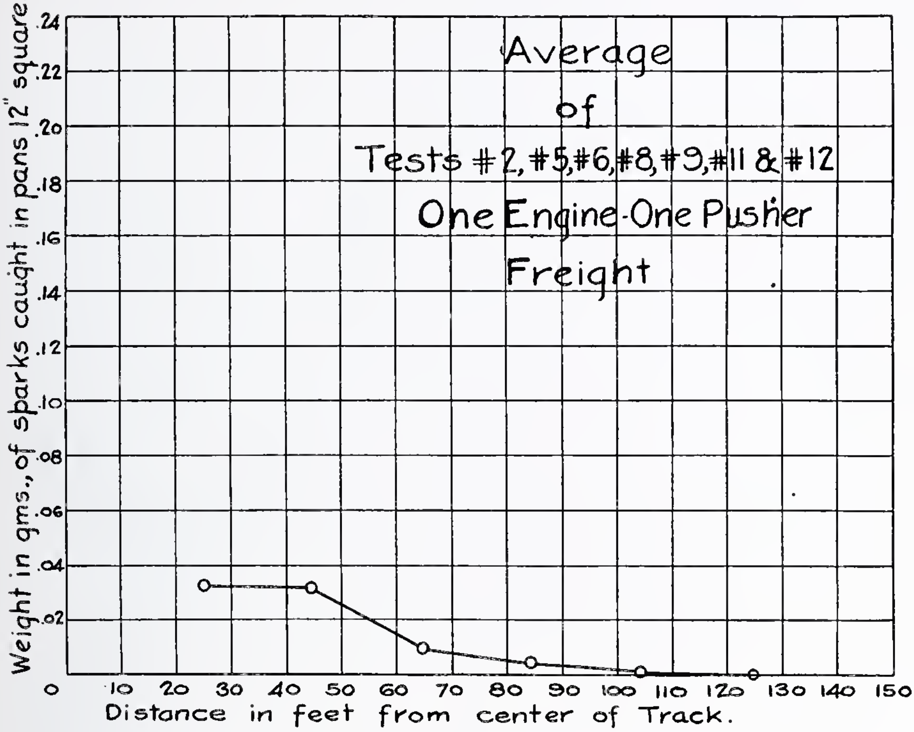


FIG. 83.—Average results one locomotive and one pusher in freight service.

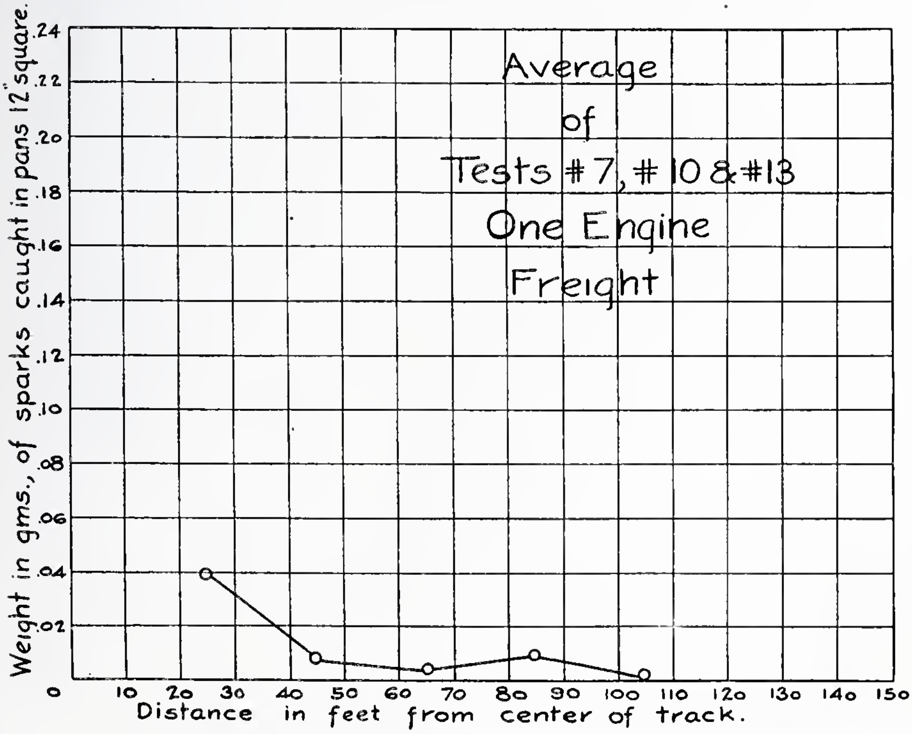


FIG. 84.—Average results one locomotive in freight service.

The variations in locomotive loading did not have an appreciable effect on the amount of sparks scattered to the zone beyond 25 feet from the track. This is especially revealed by Figures 82, 83 and 84, which represent the average results of the three groups of tests, 1, 2, and 3, respectively.

Concerning the effect of wind velocities on spark distribution, it appears, from the results presented, that high wind rates have little effect on the distance to which the bulk of locomotive sparks are scattered. Thus, the quantity of sparks caught in the 25- and 45-foot rows of pans during all the tests when the wind was blowing 10 to 20 miles per hour equaled approximately 85% of the total quantity caught. What does seem to happen when high winds prevail is that traces of spark material are carried farther to the right or left of the locomotive providing the wind is blowing approximately at right angles to the track. No spark traces were detected beyond 85 feet at the lower wind velocities, 0 to 6 miles per hour. At the higher velocities, 10 to 20 miles per hour, traces were located as far removed as 150 feet, but not beyond.

## III. THE COTTON BELT TESTS

The Cotton Belt Tests were conducted during March, 1918, on the main line of the St. Louis & Southwestern Railway Company just east of the shops of the company at Pine Bluff, Arkansas. The purpose of the tests was to determine the extent to which sparks were scattered by a certain locomotive, as well as the fire liability of these sparks when they struck the ground.

**14. Test Preparations.**—The locomotive employed for observation in this case was Cotton Belt No. 518 which had been specified in damage proceedings as having started a fire at the Pine Bluff compress located along the right of way of the railroad. The locomotive was equipped with a standard "Master Mechanics" front end. Inspection revealed that the condition of the front end was good. During the test runs the locomotive was loaded to its standard ratings.

Table XVI.—General Conditions—Cotton Belt Tests

| Test number | I | II | III | IV |
|---|---|---|---|---|
| Direction of wind | S.W. | Very slight S.W. | Very slight S.W. | Light S.W. |
| Temperature—Deg. F. | 73.4 | 73.4 | 73.4 | 75.2 |
| Condition of weather | Very slightly cloudy | Partially cloudy | Partially cloudy | Partially cloudy* |
| Velocity of wind† | 12 to 15 miles per hour | 12 to 15 miles per hour | 12 to 15 miles per hour | 10 miles per hour† |
| Speed M.P.H. | 6.8 | 8.1 | 15 | 15.1 |
| Position throttle | ½ throttle | ½ throttle | Wide open | Wide open |
| Position of reverse lever | 5 from center<br>8 from corner | 5 from center<br>8 from corner | In corner | In corner |
| Character smoke | Heavy dark | Fairly heavy smoke | Heavy exhaust light smoke | Heavy exhaust light smoke |
| Boiler pressure | 200 | 200 | 200 | 200 |
| Condition of fire | Heavy thick | Heavy thick | Heavy thick | Heavy thick |

* Floating clouds.
† Wind varying constantly in velocity.

The plot of ground staked out for pan locations was 50 feet wide and 150 feet long. The gradient of the track at the plotted ground was such that the locomotive had to work fairly hard with a full tonnage train. Three rows of stakes were laid out perpendicular to the track, 25 feet apart, and 11 rows parallel to the track 15 feet apart. The first parallel row was 15 feet from the track. The size of the pans used was the same as the size of those described in previous tests. They were lined with paraffine, cotton fleece, dry cotton lint, and dry cotton bagging in fine shreds. The first row of stakes was equipped with the cotton fleece and cotton lint lined pans, the next with the bagging shred-lined pans, and the last with the paraffine lined pans.

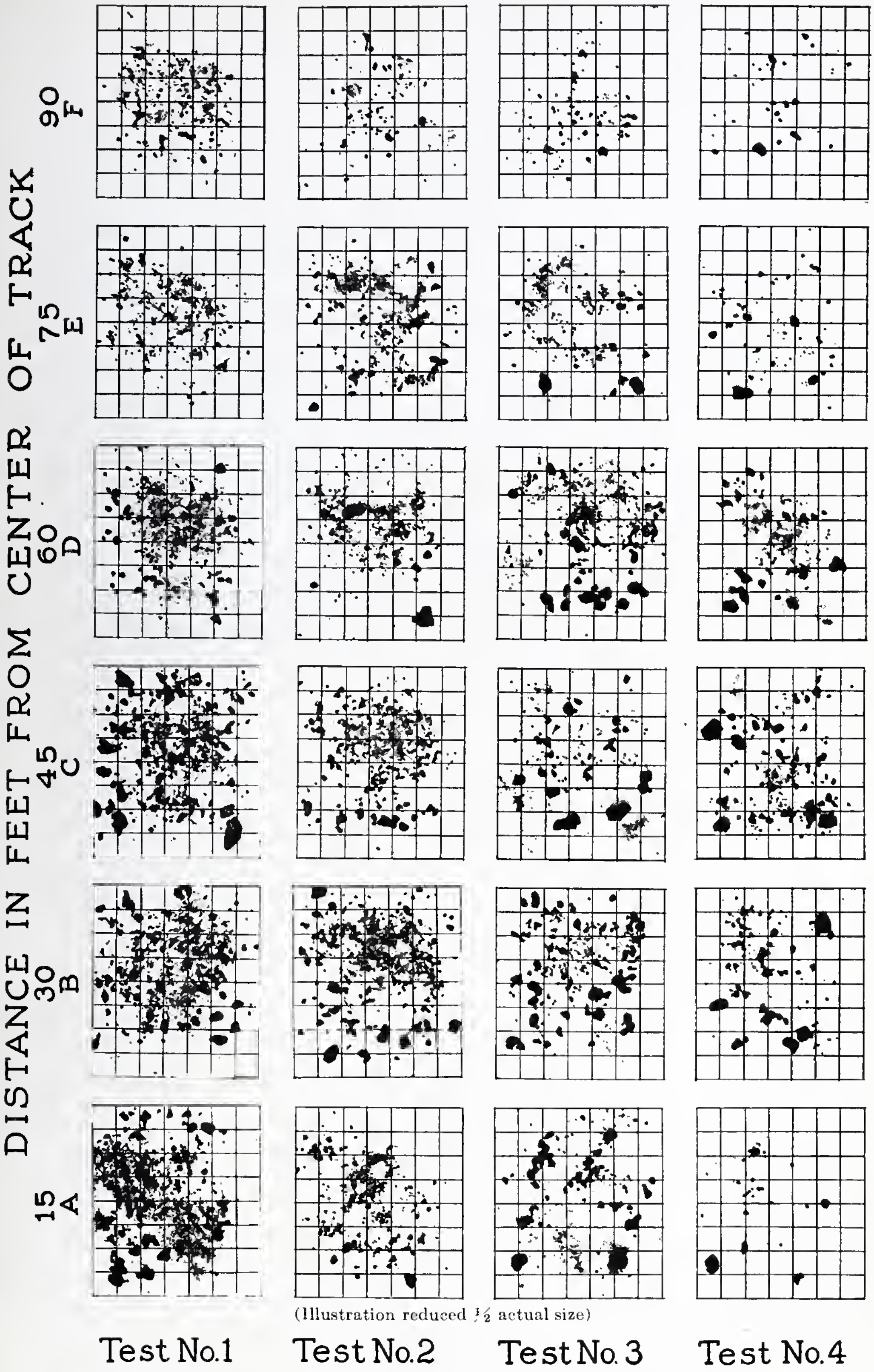
The test and observation procedure was similar to that pursued in the other tests already described. Four tests in all were conducted under the general conditions indicated in Table XVI.

**16. Summary of Results.**—The observed and tabulated data secured from these Cotton Belt tests confirmed the results secured from both the Monon and Lake Erie and Western Railroad tests as far as spark distribution and fire liability is concerned.

Thus no sparks were caught in any of the pans beyond 120 feet from the center of the track. The composition of the spark

### TABLE XVII.—OBSERVED DATA—COTTON BELT TESTS

| Distance in feet from center of track | | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Row | No. pans | A | B | C | D | E | F | G | H | I | J |
| | | | | | | Test I | | | | | |
| R4 | Cotton fleece<br>Lint cotton | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | None bottled<br>Nothing<br>Nothing | Nothing<br>Nothing |
| R5 | Bagging | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| R6 | Paraffine | 1 large sticking | 3 very small sticking | 3 small sticking | Fine trace, nothing sticking | Fine trace, nothing sticking | Fine trace, nothing sticking | Fine, no sticking | Fine, no sticking | Nothing | Nothing |
| | | | | | | Test II | | | | | |
| R4 | Cotton fleece | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| | Lint cotton | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | None bottled<br>Notning | Nothing |
| R5 | Bagging | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| R6 | Paraffine | Nothing | Nothing | Nothing | 1 very small slight sticking | Nothing | 1 small sticking | Nothing | Small specks | Nothing | Very small amount black specks |
| | | | | | | Test III | | | | | |
| R4 | Cotton fleece<br>Lint cotton | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| R5 | Bagging | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| R6 | Paraffine | 6 sticking, no melting | 2 sticking, very small | 1 sticking, no melting | | | | | | | |
| | | | | | | Test IV | | | | | |
| R4 | Cotton fleece<br>Lint cotton | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing | Nothing<br>Nothing |
| R5 | Bagging | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing | Nothing |
| R6 | Paraffine | Nothing | Nothing | Nothing | 7 very small sticking | 6 very small sticking | Few fine | Few very fine | Few very fine | Few very fine | Nothing |



(Illustration reduced ½ actual size)

Fig. 85.—Size and density of sparks caught in test pans one foot square. Cotton Belt Tests. The small squares on cross-sections are ¼ inch by ¼ inch. The sizes of the individual sparks caught in relation to those ¼ inch squares is therefore clearly shown.

material falling in the zone between 100 and 120 feet was mostly soot, and dust. No sparks were caught beyond 75 feet from the center of the track which were warm enough even to stick slightly to the surface of the paraffine in the pans. The size of the largest sparks caught, as will be noted by referring to Figure 85, is comparatively small. They are mostly in the ⅛-inch class. From this size they grade down to very minute particles less than a pinhead in size.

It is especially significant in this series of tests that no spark was caught which was hot enough to melt paraffine or to ignite, scorch, or even discolor any of the highly combustible materials in the other pans. This is quite conclusive evidence, as judged by the laboratory results described in Chapter VII, that all of the sparks caught were well under the temperature range at which sparks are capable of starting field combustibles to burn. This observation, when supplemented by the small size of the sparks caught, becomes doubly true.

## IV. THE BIG FOUR TESTS

These tests were made in October, 1920, on the Cleveland, Cincinnati, Chicago & St. Louis Railroad—Big Four—to determine, among other things, the extent to which sparks are scattered by modern heavy locomotives, the height to which sparks ascend, and the influence of various conditions of operation on spark phenomena in general.

The location selected for these tests was on the Big Four Railroad at Summit, just west of Lafayette, Indiana. This place was chosen in order to make the tests along a stretch of railroad where, owing to grade conditions, the locomotives, as they passed the observation ground, would be obliged to work very heavily. East of Summit the grade is 1.16% and from Summit west to Balls it is 1.10%. At the exact point where the test grounds were located, in between the two grades indicated above, the track is level for a short distance over a curve of 2%. Thus the locomotive crews would take

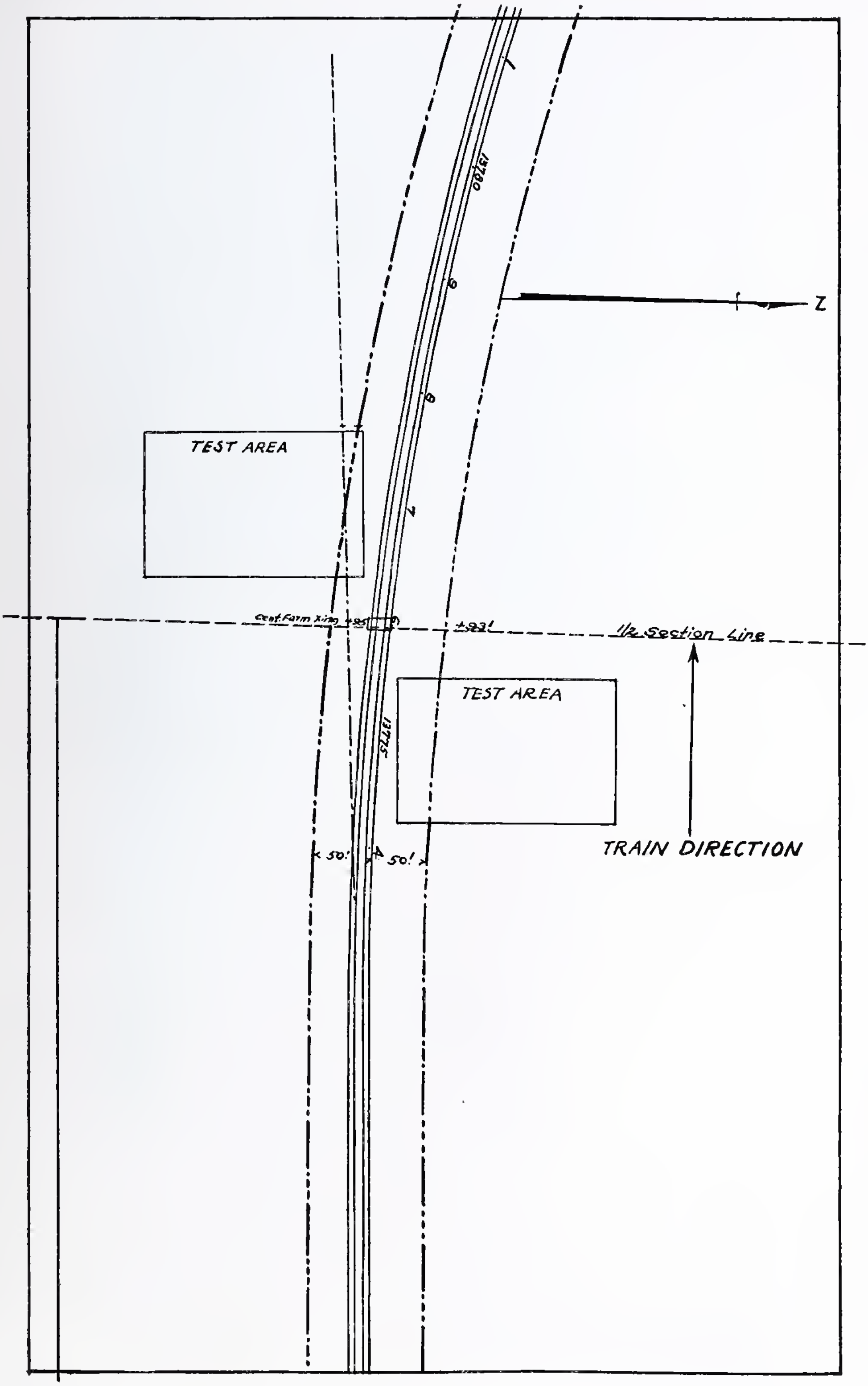


Fig. 86.—Layout of test track stretch and observation grounds. Big Four Tests.

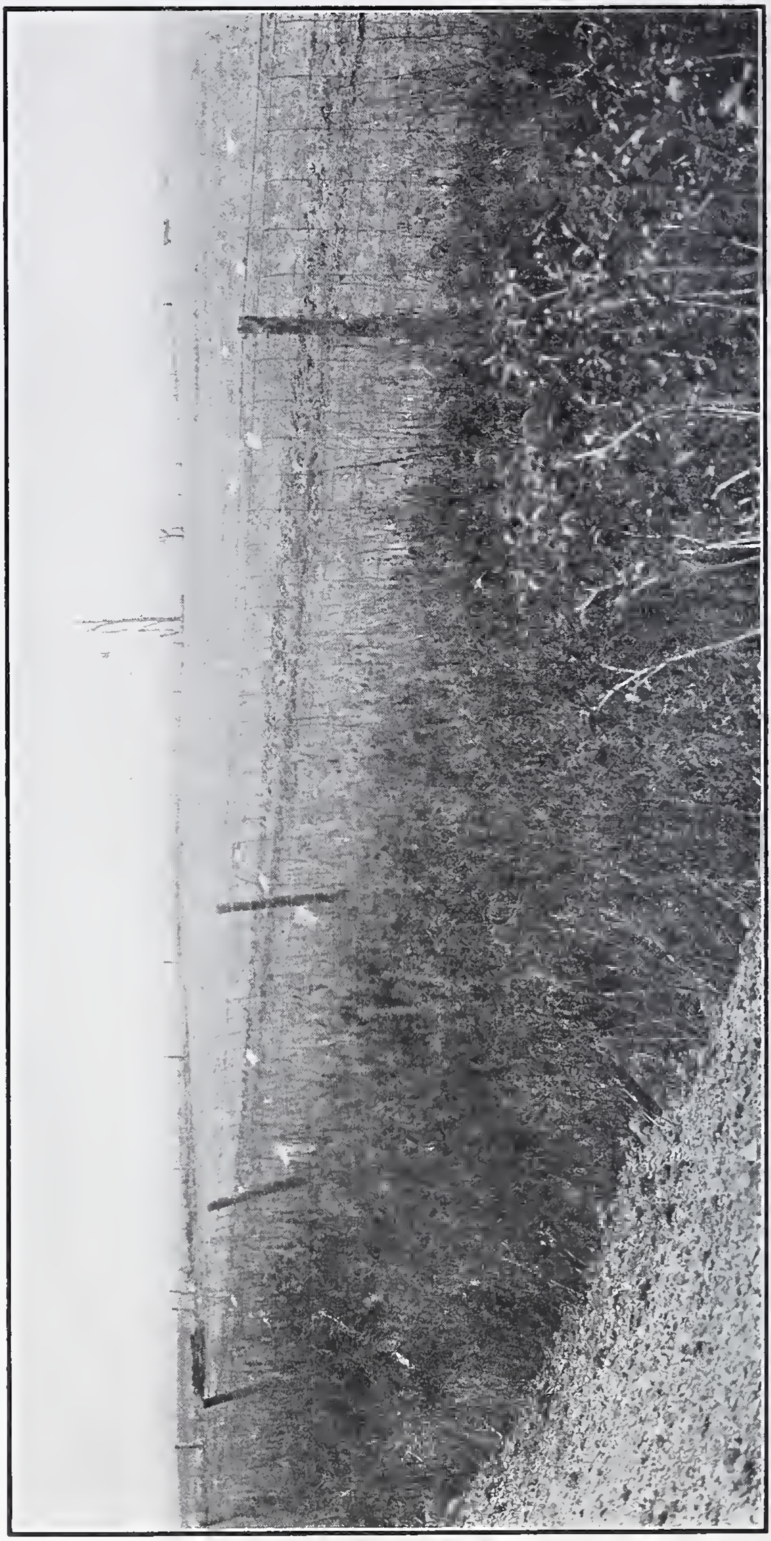
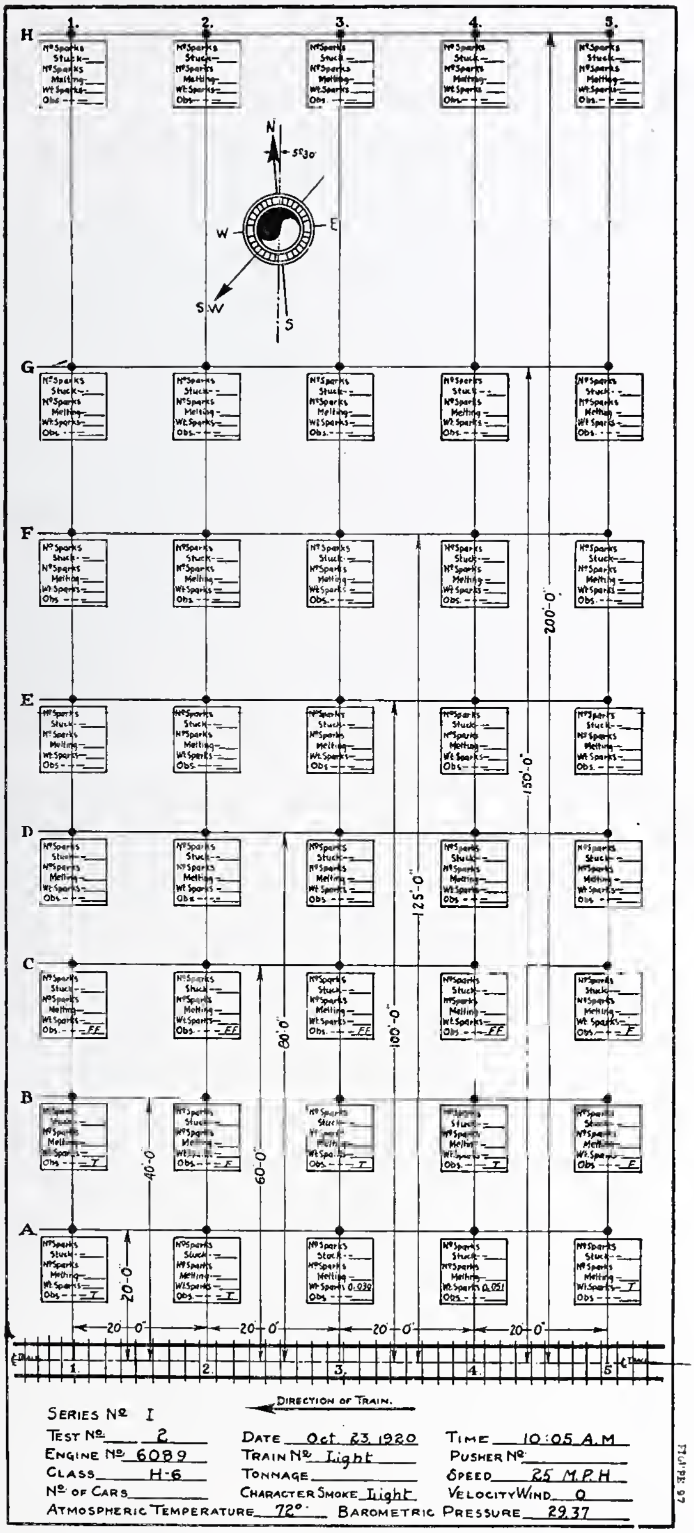


Fig. 87.—The observation ground with pans in place ready for test. Big Four Tests.



Series Nº I
Test Nº 2
Date Oct 23 1920
Time 10:05 A.M
Engine Nº 6089
Train Nº Light
Pusher Nº
Class H-6
Tonnage
Speed 25 M.P.H
Nº of Cars
Character Smoke Light
Velocity Wind 0
Atmospheric Temperature 72°
Barometric Pressure 29.37

FIG. 88.—Graphical layout of test grounds showing relation of pans to tracks. This layout sheet as illustrated above was used as the standard data sheet throughout the Big Four Tests.

advantage of this short stretch and accelerate their trains for the next grade by working the locomotives as hard as possible. A layout of the track arrangement and the relation of the observation grounds thereto is shown in Figure 86.

**17. Test Preparations.**—In preparation for these tests the ground along the tracks was accurately laid out by transitmen and the points at which pans were to be placed marked by 8 rows of stakes, 5 stakes to each row. These stakes were located as follows: A row of 5 stakes on a line running parallel with and 20 feet from the center of the track; a second row 40 feet from the center; a third row at 60 feet; a fourth row at 80 feet; fifth row at 100 feet; sixth row at 125 feet; seventh row at 150 feet; and the eighth row at 200 feet. This makes 5 rows of pans—8 pans each —running back from the track at right angles to the center line. A photograph of the test grounds on one side of the track is shown in Figure 87 and a graphical layout of the grounds drawn to scale is shown in Figure 88.

The locomotive employed for the principal tests was a standard Big Four freight Mikado, No. 6089, built by the Baldwin Locomotive Company in 1918, with the following specifications:

| | |
|---|---|
| Diameter and stroke of cylinders | 26 × 30 inches |
| Diameter of drivers | 63 inches |
| Boiler pressure | 200 pounds |
| Tubes, number large | 40–5½ inches |
| Tubes, number small | 216–2¼ inches |
| Tubes, length over sheets | 19 ft. 0 inches |
| Heating surface tubes | 3497 sq. ft. |
| Heating surface fire box and arch tubes | 280 sq. ft. |
| Total heating surface | 3777 sq. ft. |
| Heating surface superheater | 882 sq. ft. |
| Grate area | 66.77 sq. ft. |
| Weight on front truck, working order | 20,100 pounds |
| Weight on drivers, working order | 220,000 pounds |
| Weight on rear truck, working order | 51,900 pounds |
| Total weight of engine, working order | 292,000 pounds |
| Weight of tender, loaded | 185,400 pounds |

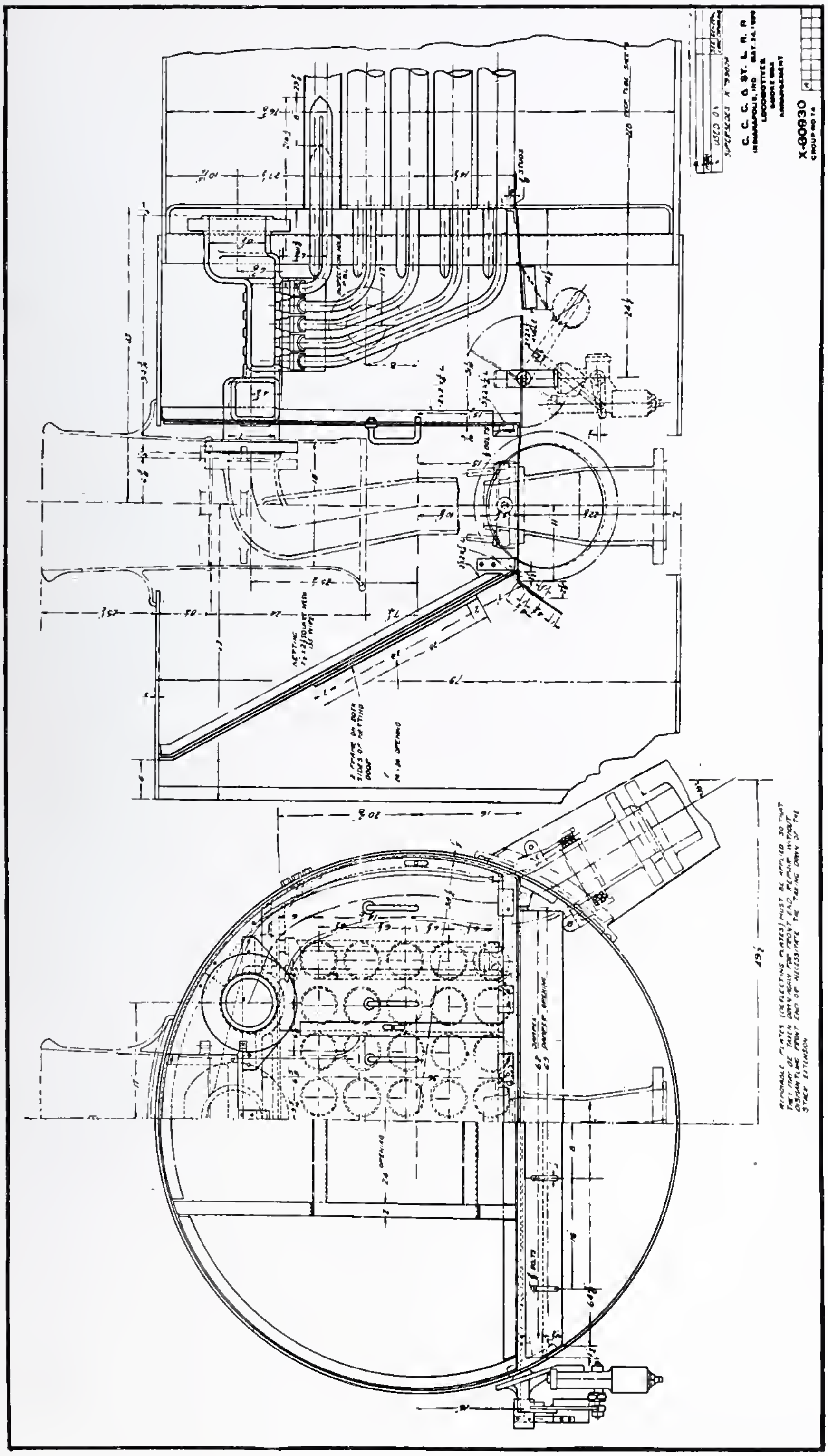


FIG. 89.—Construction of front end and layout of netting. Big Four Test locomotive No. 6089.

| | |
|---|---|
| Weight of tender, empty | 68,600 pounds |
| Coal capacity of tender | 16 tons |
| Water capacity of tender | 10,000 gals. |
| Maximum tractive force | 54,700 pounds |

This locomotive was especially equipped for the tests and had a crew of experienced men to operate it. Arrangements had previously been made so that five draft readings could be taken: (1) in the fire box, (2) at the base of the stack, (3) in front of the flues, (4) in the smoke box, and (5) above the ash pan. The temperature at the front end and a gauge reading of the back pressure was also taken.

The construction of the front end and the arrangement of the netting of this locomotive are shown in Figure 89.

In addition to observations taken on this particular locomotive, other observations were taken on miscellaneous freight, passenger and work-train locomotives passing the test ground while in actual service.

On the Mikado test locomotive No. 6089 a full throttle opening was maintained and the maximum cut-off was used throughout the entire series of tests. Inasmuch as the locomotive was run without a train of cars, the load was secured by maintaining brake applications on the drivers at pressures to bring about desired operating conditions for speed, reverse lever position, throttle opening, front end draft and the like.

The apparatus used in these tests, in addition to the pans which were of the standard type already described, was similar to that used in the Monon tests, with the addition of a transit to measure the height to which locomotive sparks were projected.

**18. Method of Testing.**—The methods of testing employed were also similar to those of the previous tests. Nine series of tests in all were run, four of which, however, were for special purposes. These will be described and their results analyzed in the last chapter. The five remaining ones, conducted under the conditions indicated, were numbered as follows:

Series No. I—Four tests using square-mesh netting—2½ × 2½ mesh, .135 wire—in good condition; an exhaust nozzle opening of 5¾ inches; throttle wide open; and the locomotive stoker fired.

Series No. II—Four tests using square-mesh netting in good condition; nozzle opening 5¾ inches; throttle wide open; and the locomotive hand fired.

Series No. VII—Six tests made on miscellaneous freight locomotives in actual service.

Series No. VIII—Six tests made on miscellaneous passenger locomotives in actual service.

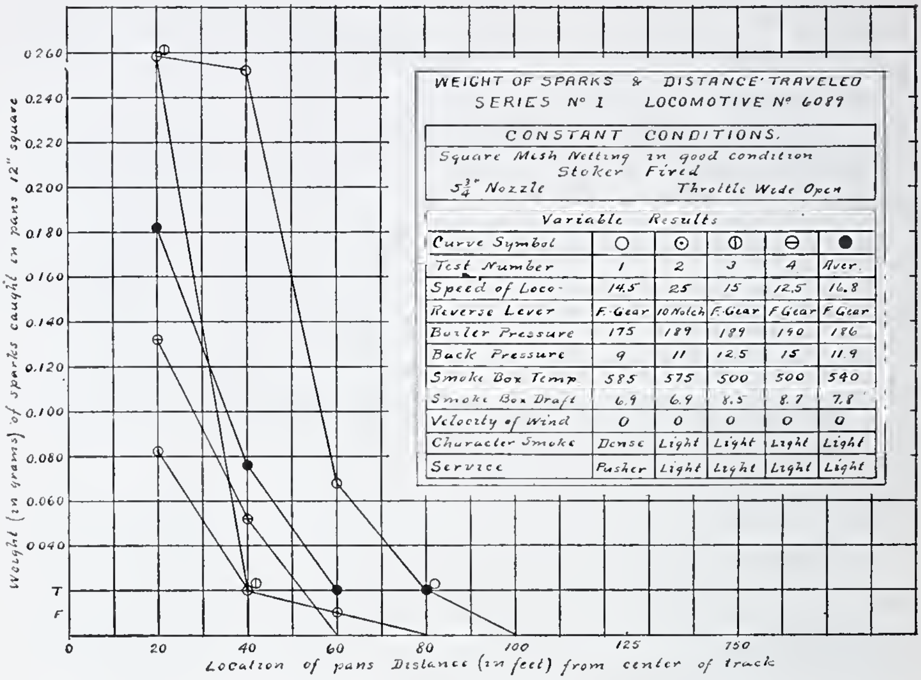
Series No. IX—Four tests made on a work-train locomotive hauling cars of gravel from a near-by pit.

Shortly before each test the pans were set in their positions at the stakes. In noting the conditions of sparks as they were found on the paraffine pans, arbitrary standards based on the results of tests described in Chapter VII were established for comparative purposes, as follows:

1. Sparks hot enough to melt the paraffine.
2. Sparks hot enough to stick to the paraffine.
3. Loose sparks on the surface of any of the pans in sufficient quantity to be weighed. These were carefully brushed into small bottles, each bottle was labeled with a location symbol, kept, and later on, weighed.
4. Loose sparks on the surfaces of the pans in quantities not sufficient to warrant weighing were designated a "Trace."
5. When only a very few loose sparks appeared on the surface of the pan, and these sparks were very small, they were classified as "Faint trace."
6. When the faint trace on the surface of the pans appeared to be only fine dust, it was so noted.

The readings of the pans for the various tests were entered on the log sheets and such sparks as were collected and bottled were very carefully weighed in the laboratory and the results plotted as shown in Figures 90 to 94 inclusive. In making these tabulations all weights less than 0.040 grams were called a "Trace."

At the test ground, readings were also made of the atmospheric temperature and the direction and velocity of the wind.



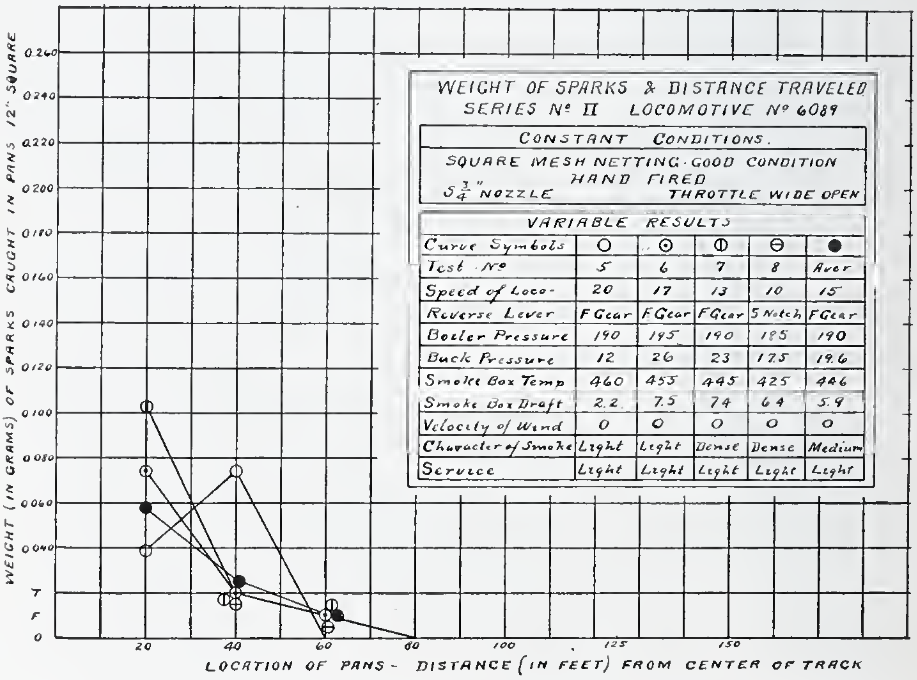
WEIGHT OF SPARKS & DISTANCE TRAVELED
SERIES No I LOCOMOTIVE No 6089

CONSTANT CONDITIONS.
Square Mesh Netting in good condition
Stoker Fired
$5\frac{3}{4}$" Nozzle Throttle Wide Open

Variable Results

| Curve Symbol | ○ | ⊙ | ⦶ | ⊖ | ● |
|---|---|---|---|---|---|
| Test Number | 1 | 2 | 3 | 4 | Aver. |
| Speed of Loco- | 14.5 | 25 | 15 | 12.5 | 16.8 |
| Reverse Lever | F. Gear | 10 Notch | F. Gear | F Gear | F Gear |
| Boiler Pressure | 175 | 189 | 189 | 190 | 186 |
| Back Pressure | 9 | 11 | 12.5 | 15 | 11.9 |
| Smoke Box Temp | 585 | 575 | 500 | 500 | 540 |
| Smoke Box Draft | 6.9 | 6.9 | 8.5 | 8.7 | 7.8 |
| Velocity of Wind | 0 | 0 | 0 | 0 | 0 |
| Character Smoke | Dense | Light | Light | Light | Light |
| Service | Pusher | Light | Light | Light | Light |

FIG. 90.—Relation between weight of sparks caught and distance from center of track. Big Four Test Series No. 1. Locomotive stoker fired, square mesh netting.



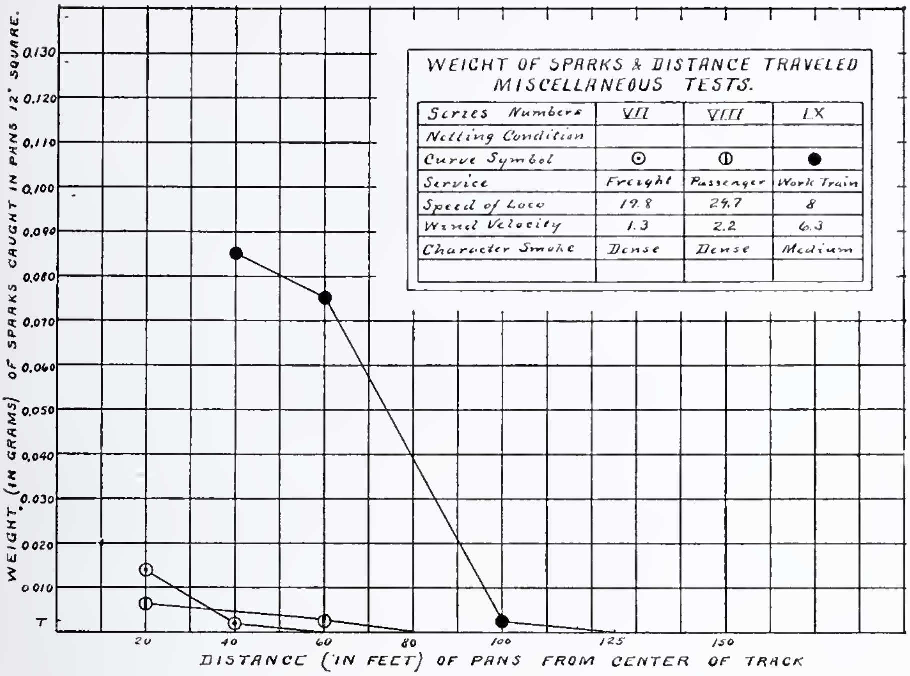
WEIGHT OF SPARKS & DISTANCE TRAVELED
SERIES No II LOCOMOTIVE No 6089

CONSTANT CONDITIONS.
SQUARE MESH NETTING · GOOD CONDITION
HAND FIRED
$5\frac{3}{4}$" NOZZLE THROTTLE WIDE OPEN

VARIABLE RESULTS

| Curve Symbols | ○ | ⊙ | ⦶ | ⊖ | ● |
|---|---|---|---|---|---|
| Test No | 5 | 6 | 7 | 8 | Aver |
| Speed of Loco- | 20 | 17 | 13 | 10 | 15 |
| Reverse Lever | F Gear | F Gear | F Gear | 5 Notch | F Gear |
| Boiler Pressure | 190 | 195 | 190 | 185 | 190 |
| Back Pressure | 12 | 26 | 23 | 17.5 | 19.6 |
| Smoke Box Temp | 460 | 455 | 445 | 425 | 446 |
| Smoke Box Draft | 2.2 | 7.5 | 74 | 64 | 5.9 |
| Velocity of Wind | 0 | 0 | 0 | 0 | 0 |
| Character of Smoke | Light | Light | Dense | Dense | Medium |
| Service | Light | Light | Light | Light | Light |

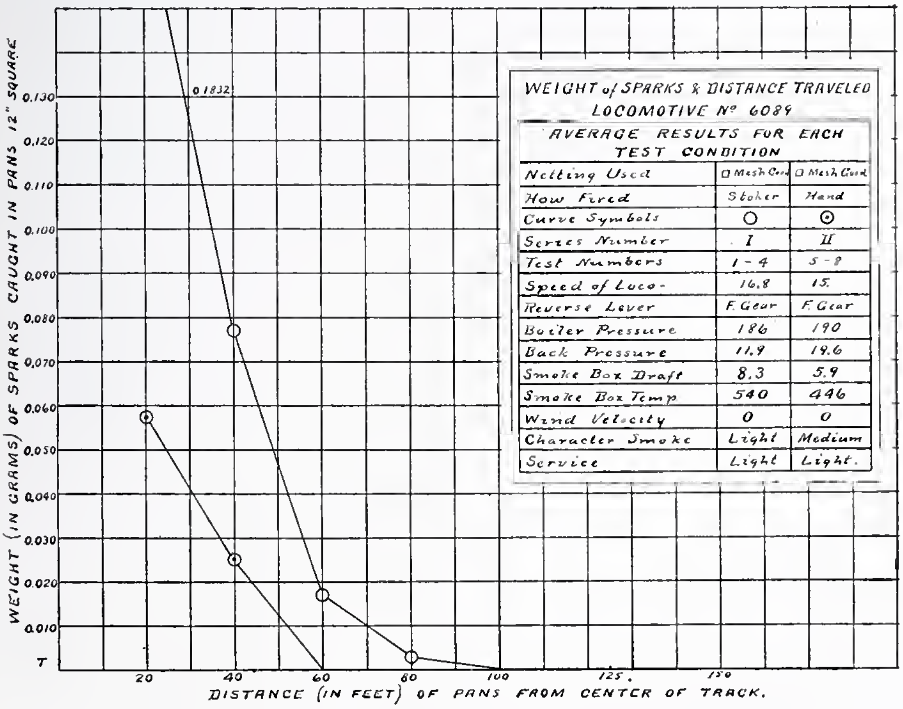
FIG. 91.—Relation between weight of sparks caught and distance from center of track. Big Four Tests Series No. II. Locomotive hand fired, square mesh netting.



WEIGHT OF SPARKS & DISTANCE TRAVELED
MISCELLANEOUS TESTS.

| Series Numbers | VII | VIII | IX |
|---|---|---|---|
| Netting Condition | | | |
| Curve Symbol | ⊙ | ⦶ | ● |
| Service | Freight | Passenger | Work Train |
| Speed of Loco | 19.8 | 24.7 | 8 |
| Wind Velocity | 1.3 | 2.2 | 6.3 |
| Character Smoke | Dense | Dense | Medium |
| | | | |

FIG. 92.—Relation between weight of sparks caught and distance from center of track. Big Four Test Series Nos. VII, VIII and IX—miscellaneous tests.



WEIGHT of SPARKS & DISTANCE TRAVELED
LOCOMOTIVE Nº 6089

AVERAGE RESULTS FOR EACH
TEST CONDITION

| Netting Used | □ Mesh Cord | □ Mesh Cord |
|---|---|---|
| How Fired | Stoker | Hand |
| Curve Symbols | ○ | ⊙ |
| Series Number | I | II |
| Test Numbers | 1 - 4 | 5 - 8 |
| Speed of Loco- | 16.8 | 15. |
| Reverse Lever | F. Gear | F. Gear |
| Boiler Pressure | 186 | 190 |
| Back Pressure | 11.9 | 19.6 |
| Smoke Box Draft | 8.3 | 5.9 |
| Smoke Box Temp | 540 | 446 |
| Wind Velocity | 0 | 0 |
| Character Smoke | Light | Medium |
| Service | Light | Light. |

FIG. 93.—Comparison spark distribution as effected by hand and stoker firing.

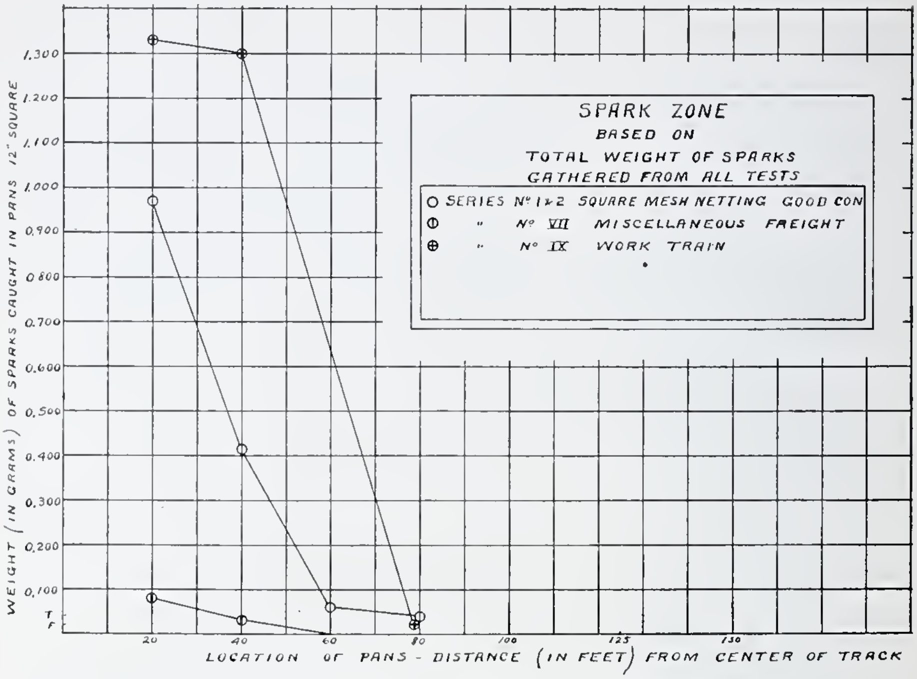


FIG. 94.—Average spark distribution for all tests.

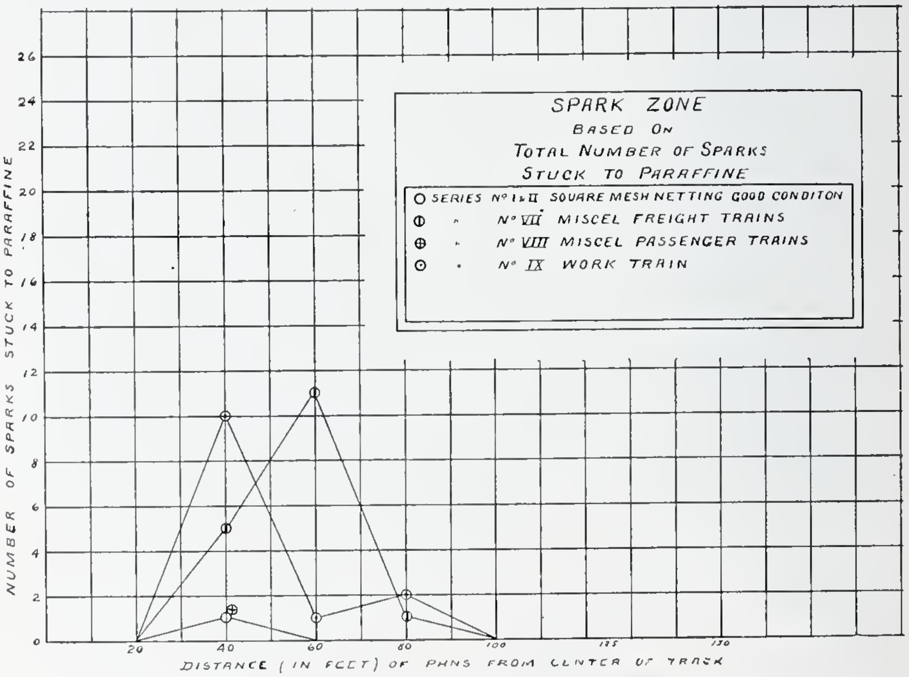


FIG. 95.—Total numbers of sparks stuck to paraffine in relation to distance from center of track. Big Four Test Series Nos. I, II, VII, VIII and IX.

**19. Data Observed and Tabulated.**—In order to make a careful study of the observations as recorded on the log sheets, the results were tabulated and arranged in three groups entitled:

Summary of data on sparks
Summary of test averages
Number of sparks stuck

From these tabulations other tables were prepared showing a summary of the average weight of sparks caught in the pans for each row; a summary of the total number of sparks stuck for each row of each series and the average per test for each series; and a summary of test averages for the various tests conducted. The curves as shown in Figures 90 to 95 were plotted from the resultant data of these tables.

The results of Test Series No. I, i.e., with Mikado freight locomotive No. 6089, stoker fired, and equipped with $2\frac{1}{2} \times 2\frac{1}{2}$ square mesh netting, in good condition are shown in the table and curves of Figure 90. The test conditions are indicated, together with the quantity of sparks distributed over the pans of the test area. Similar data is presented by Figure 91 for Test Series No. II, conducted under conditions paralleling those of Series No. I except for the fact that the locomotive was hand instead of stoker fired. Figure 92 presents the spark distribution results based on the miscellaneous tests, i.e., Series VII, VIII, and IX, made with freight, passenger, and work-train locomotives in regular service.

Figure 93 has been prepared to show the effect of stoker-firing a modern locomotive on spark distribution as compared with hand-firing the same locomotive. Figure 94 shows the average spark distribution results of all the tests. Table XVIII indicates the number of sparks which fell on the various pans, row by row, which were warm enough on landing to stick to the paraffine. This same information is presented graphically in Figure 95.

TABLE XVIII.—NUMBER OF SPARKS STUCK, TOTAL FOR EACH ROW AND SERIES AND AVERAGE FOR EACH SERIES

Big Four Tests, Series I, II, VII, VIII and IX

| Rows of pans | Test conditions constant | | | | |
|---|---|---|---|---|---|
| | I | II | VII | VIII | IX |
| | Sq.-mesh netting good cond. stoker fired | Sq. mesh netting good cond. hand fired | Misc. frt. locos. | Misc. pas. locos. | Misc. work train locos. |
| A............... | 0 | 0 | 0 | 0 | 0 |
| B............... | 1 | 0 | 5 | 1 | 10 |
| C............... | 0 | 0 | 11 | 0 | 1 |
| D............... | 0 | 0 | 1 | 0 | 2 |
| Total.......... | 1 | 0 | 17 | 1 | 13 |
| Number of tests.. | 4 | 4 | 6 | 6 | 4 |
| Average per series | 0.25 | 0 | 2.83 | 0.17 | 3.25 |

A careful study of all the curves presented in Figure 95 again clearly shows that the zone into which the great bulk of sparks falls is within 50 feet of the track. This has been found to be true of the smaller locomotives which were observed in the previous tests. It is again true of the large Mikado locomotive observed in these tests. Of the sparks which fell hot enough to stick to paraffine, as shown by Figure 95, 17 or 55% dropped within the 50-foot zone area, whereas, only 45% fell beyond this area, and no farther beyond than 80 feet from the track center.

In comparing the test results secured while the locomotive was stoker-fired with those secured during hand-firing, it will be noted that the quantity of sparks scattered is apparently three times as great. This confirms the findings of the laboratory tests described in Chapter VI made with a Baltimore & Ohio Mikado locomotive at the Engineering Experiment Station, University of Illinois, on six grades of Illinois coal. Despite, however, the increased quantity of sparks ejected from this

Big Four locomotive while stoker-fired, it still remains true that the great bulk of sparks fell within the 50-foot zone along the right of way, that they were small in size, and that their fire carrying properties were likewise negligible.

**20. Tests to Determine Height to Which Sparks Ascend.**—In order to determine the height to which sparks rise after leaving the locomotive stack, a transit was set up at a point 300 feet distant from the center of the track, so located that a large tree on the opposite side of the track was perpendicularly in line with the transit. The readings of the height of the sparks were made at night, in Series VI on Big Four Consolidation Locomotive No. 6675, running light, with brakes applied, however, to secure the load.

The readings were made by sighting along the barrel of the telescope. In this way the transit man could easily follow the movement of the locomotive and of the sparks at the same time and note when the transit was in line with the tree. The angles read were accurate to at least one-half of a degree, which was considered close enough for the purpose. Table XIX shows the observations made during this phase of the Big Four tests. This information will prove of use when determining spark distribution by mathematical calculations.

Table XIX.—Height to Which Live Sparks Ascend Series No. VI
Big Four Tests

| Test No. | Speed of locomotive in M.P.H. | Angle of elevation | Max. height of sparks | |
|---|---|---|---|---|
| | | | Track level | Top of stack |
| 122 | 10 | 23°- 0 | 127′ | 112′-1″ |
| 123 | 15 | 29°-30′ | 171′ | 156′-1″ |
| 124 | 12 | 27°-30′ | 156′ | 141′-1″ |
| 125 | 12 | 31°- 0′ | 180′ | 165′-1″ |
| 126 | 12 | 30°-40′ | 178′ | 163′-1″ |
| 127 | 12 | 31°-50′ | 184′ | 169′-1″ |
| 128 | 12 | 33°-30′ | 199′ | 184′-1″ |
| Average maximum height of live sparks. | | | 170.7′ | |

**21. Effect of Locomotive Operating Conditions on Spark Distribution.**—It was pointed out in Chapter VI, that the main conditions which affect spark formation are (1) the size of the locomotive, (2) the draft or the load at which the locomotive works, (3) the characteristics of the coal, and (4) the method of firing the coal. Obviously, in conjunction with the conditions prevailing on the road, arising from the speed with which the locomotive moves and the velocity and direction of the wind encountered, an almost unlimited series of combinations may arise which will affect spark distribution in a great variety of ways.

When the Big Four tests were planned, this fact was taken into consideration. Consequently some of the observations taken had the object in view of shedding additional light on the relationship between the factors which affected spark formation and those which affected spark distribution.

The size of the locomotive, as already indicated, does not affect the distribution of the sparks sidewise along the right of way. The greater bulk of all the sparks ejected from the locomotive stack, persist in falling to the front and rear rather than to the right and left of the locomotive.

Furthermore, a study of all the data reveals the fact that the load at which the locomotive works, heavy or light, does not materially affect the distribution of sparks adjacent to the right of way. In the Monon Tests, as will be remembered the load varied from practically zero (locomotive and caboose) to 100%, increasing in 25% increments. Figures 96 and 97 show how the locomotive draft conditions varied in Series I and II of the Big Four Tests. Inasmuch as locomotive draft and nozzle back pressure are primarily a function of the load imposed upon the locomotive, an idea is secured of the variations in working conditions to which this Big Four locomotive was subjected. Despite the wide ranges in loading, spark distribution crosswise to the line of roadway was fairly constant.

**22. Wind and Spark Distribution—Theoretical Calculations.**—Inasmuch as these Big Four Tests tended to reaffirm the previous

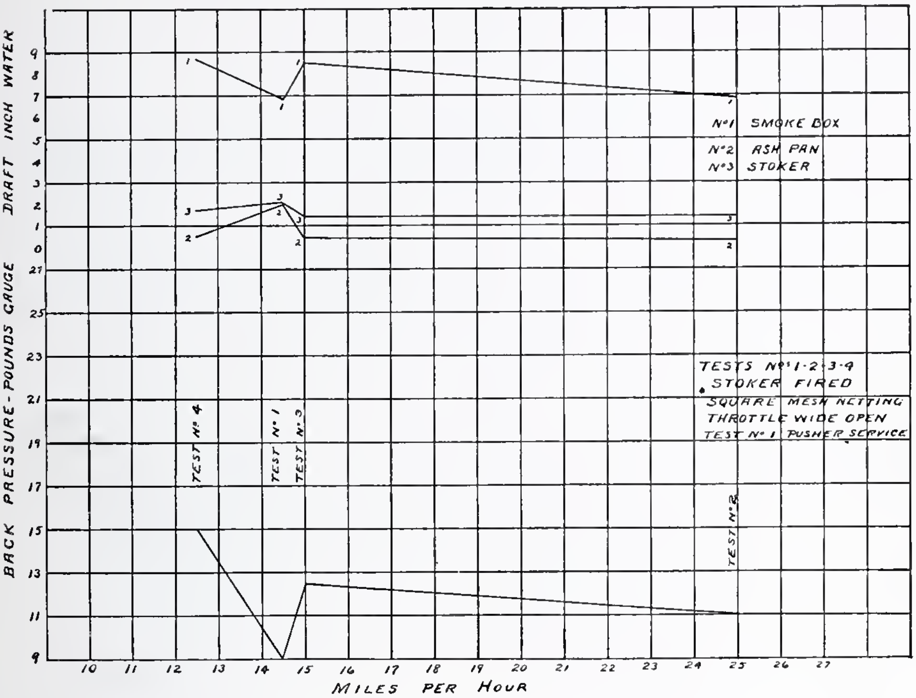


FIG. 96.—Locomotive draft conditions. Big Four Tests Nos. 1, 2, 3, 4. Series I.

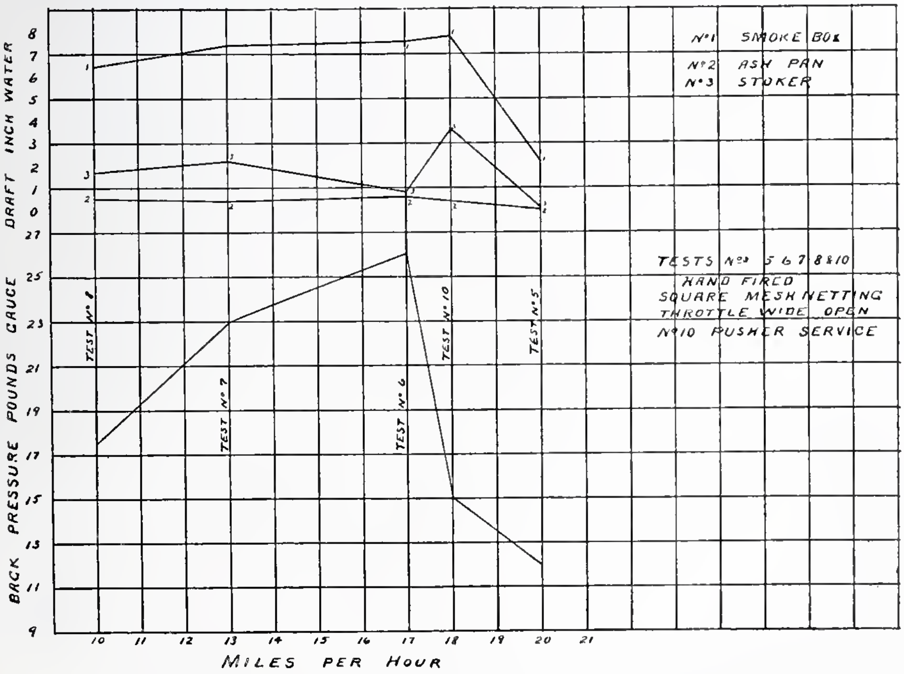


FIG. 97.—Locomotive draft conditions. Big Four Test Series II.

findings, namely, that the average wind velocities have very little influence on spark distribution, an attempt was made to check this result mathematically. Data with reference to both the value of $g$ (rate of acceleration due to gravity in air) of sparks and the height to which they are projected from the locomotive has already been determined. The computations in question which follow were based simply on one combination of conditions and are not complete, due to the fact that tests have not yet been conducted for use in their connection.

The calculations made were based on a combination of maximum conditions, namely:

1. A maximum measured height of sparks of 220 feet when the locomotive was working at its maximum capacity.
2. A maximum speed of 25 miles per hour with the locomotive sustaining the greatest tractive effort.
3. A wind velocity of 10 miles per hour perpendicular to the motion of the locomotive.

The initial velocity, relative to the locomotive, of the spark traveling to a height of 200 feet can be found by the formula

$V = \sqrt{2\,gh}$, where
$V$ = Initial velocity in feet per second
$g$ = Acceleration of gravity or 22.7 feet per second.[1]
$h$ = Height in feet to which spark is ejected or 200 feet.

Then, in the equation, $V = \sqrt{2 \times 22.7 \times 200} = 95.3$ feet per second.

The velocity of the locomotive traveling 25 miles per hour is equal to 36.7 feet per second.

The velocity of the wind traveling 10 miles per hour is equal to 14.7 feet per second.

Combining the wind and locomotive velocities, the resultant velocity equals $\sqrt{(14.7)^2 + (36.7)^2}$, or 39.5 feet per second. The angle of this resultant with the center line of the track is $21° 54'$.

---

[1] The figure 22.7 for g applying to locomotive sparks was experimentally determined by Dr. W. F. W. Goss. For a description of his tests and calculations see "Locomotive Sparks," pp. 136–139.

Next combining the resultant velocity of the wind and locomotive with the initial relative velocity of the spark, which is assumed to be vertical, the final absolute velocity resultant is found to be equal to $\sqrt{(95.3)^2 + (39.4)^2}$, or 103.2 feet per second. The angle of this resultant, or the angle of projection, with the horizontal, is 67° 30′.

From the equation for the theory of projectiles

$$x = v \,.\, \cos \phi \,.\, t$$
$$y = v \,.\, \sin \phi \,.\, t - 16.1\, t^2$$

Where

$x$ = ½ horizontal distance projectile travels in feet along the X-axis of the parabolic curve.

$y$ = height projectile reaches in feet along the Y-axis
$v$ = initial velocity along the angle of projection
$\phi$ = angle of projection
$t$ = time of flight

substituting these values in the above equations and solving first for the value of t and finally the value of x,

In equation, $y = v \,.\, \sin \phi \,.\, t - 16.1\, t^2$

$$200 = 103.2 \,.\, \sin 67° 30' \,.\, t - 16.1\, t^2$$
$$16.1\, t^2 - 95.35\, t + 200 = 0$$

solving this equation gives $t = 3.46$ seconds.

Now in equation, $x = v \,.\, \cos \phi \,.\, t$

$$x = 120 \,.\, \cos 64° 30' \,.\, 3.46$$
$$= 120 \times .3827 \times 3.46$$
$$= 158.9 \text{ feet.}$$
$$2x = 317.8 \text{ feet, or the horizontal distance traveled.}$$

This direction of travel, however, is at an angle of 21° 54′ with the center line of the track. Therefore, the perpendicular distance from the center of the track which the spark will travel before striking the ground will be

$$317.8 \times \sin 21° 54', \text{ or } 118 \text{ feet.}$$

This result, 118 feet, agrees very well with actual test indications as shown by quite a few of the figures referred to in this chapter.

In other words, given maximum conditions, a locomotive spark will not travel much beyond 100 feet from the center of the track.

Theoretical comparative tables of data could be compiled by computing mathematically the distance sparks travel when acted upon by each and all of the following forces:

1. Variable height sparks are ejected from the stack.
2. Variable speed of locomotive.
3. Variable wind velocities.
4. Variable direction of the wind.

It should be noted in the computations that, in order to simplify the calculations, no allowance was made for the height of the stack. This should be taken into account in a more exhaustive study; also the disturbing influences which the hot gases, assisting in carrying the sparks from the stack, have upon the prevailing air currents; and the influence of the motion of the train itself should be considered as determining factors in a more complete analysis.

**23. General Characteristics of Locomotive Spark Distribution.** In order to shed a comprehensive light on the general nature of locomotive spark distribution, the various distribution results secured during the four tests described in this chapter together with the results secured by Dr. Goss in his experiments[1] have been converted from the weight-distance basis to the percentage-distance basis. By plotting all of these percentages against distance on one chart, a composite curve is secured which will indicate quite accurately the probable distribution of sparks from locomotives under operating conditions usually prevailing in railroad practice. Such a curve is shown in Figure 98. On the basis of this curve it is found that the total percentages of all sparks falling to either side of a locomotive are as follows:

| | |
|---|---|
| In the 50-foot zone | 83.5% |
| In the 75-foot zone | 93.0% |
| In the 100-foot zone | 98.0% |

[1] "Locomotive Sparks," Dr. W. F. M. Goss, pp. 95, 96, 97.

In the 125-foot zone 99.5%
In the 150-foot zone 99.57%
In the 200-foot zone 100.00%

**24. Conclusions as to Spark Distribution.**—The observations, data, and results in general, which have been secured from the tests described, warrant the following specific conclusions concerning the distribution of locomotive sparks in the area adjacent to railroad rights of ways:

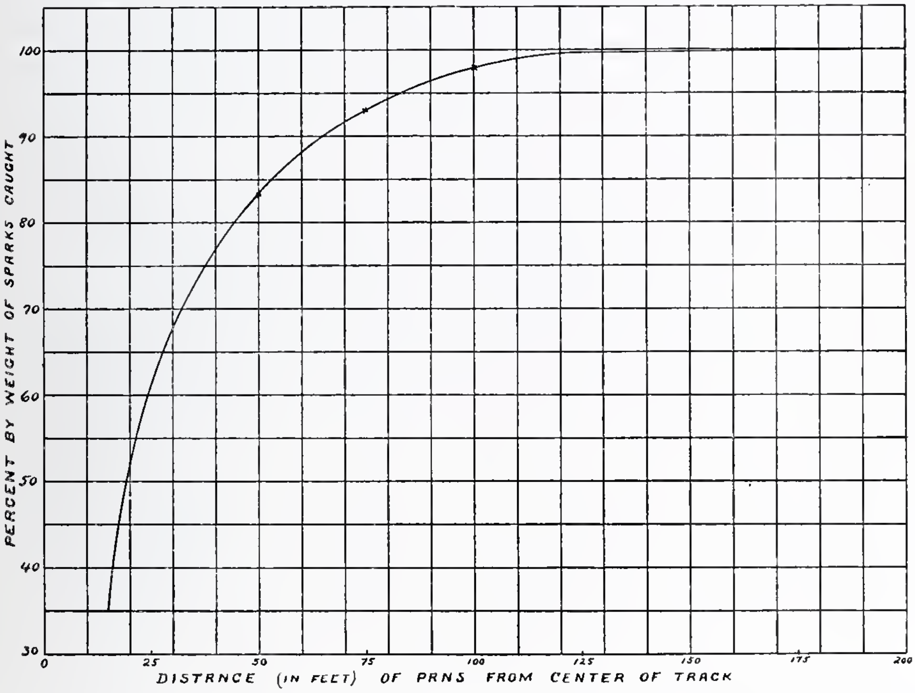


FIG. 98.—Composite spark distribution curve based on all spark distribution data of record from Gross Tests to Big Four Tests.

1. The great bulk of all locomotive sparks, i.e., 83.5% fall within the 50-foot zone paralleling the railroad track and fully 98% fall within the 100-foot zone.

2. The material which falls beyond the 100-foot zone consists of fine specks, dust and the like which is harmless.

3. Practically all sparks of definite weight and bulk fall within the 65-foot zone and the greatest portion of these falls within the 50-foot zone.

4. Practically all sparks of sufficient temperature to ignite combustibles when they reach the ground, fall within the 50-foot zone. Occasionally one finds lodgement as far out as 65 feet, but this is exceptional.

5. The number of sparks registering a temperature of 1000° to 1200° when striking the ground, is small. The size of these sparks is usually ¼ inch or less. As shown in conclusions 2 and 5 of Chapter VII, Ignition Properties of Locomotive Sparks, these sparks only become dangerous as fire starters at these temperatures when they exceed ¼ inch in size and when light winds are blowing.

6. Wind velocities up to 20 miles per hour have practically no influence on spark distribution. Beyond 20 miles an hour, however, they tend to carry the very light particles of sparks and dust a greater distance than occurs in the case of the milder winds. They do not affect the heavier or bulkier sparks to any appreciable degree. These still continue to fall within the 50-foot zone.

7. General locomotive conditions, such as size, load, method of firing, draft, back pressure do not affect the characteristics of locomotive spark distribution outside the locomotive very materially. The same percentages of all sparks ejected fall within their respective zones paralleling the roadway.

# CHAPTER IX

## LOCOMOTIVE SPARK FIRE PREVENTION

When the general conclusions of the tests described in the three preceding chapters are all considered together important truths concerning the prevention of fires from locomotive sparks become apparent. Thus the results secured from these tests should help in pointing out the direction in which further progress might be expected in reducing the fire hazard incidental to steam locomotive operation.

**1. The Bearing of Test Results Already Described on Fire Prevention.**—First and foremost the fact of greatest importance to note in this connection is that the small spark, that is the spark ¼ inch in size or less, as ordinarily released from the locomotive stack, has not the capacity to set fire by the time it reaches the ground. Hence any arrangement in the locomotive front end which will retard sparks from leaving the stack until they have either worn or burnt themselves down to ¼ inch or less in size, will, by so doing materially destroy the fire starting capacity of these sparks. Obviously, therefore, the more below the ¼-inch size it is possible to reduce sparks before releasing them from the front end without disturbing the draft function, the safer the locomotive becomes from the fire prevention standpoint.

The next point of importance to note is that the largest portion of the sparks thrown to the side of the locomotive, 83.5%, falls approximately within 50 feet of each side of the track. Included in this are the hottest and largest sparks which reach the ground. However, these sparks are only dangerous when the combination of size and temperature exceeds ¼ inch and 1000° to 1200° respectively. And only a very few sparks are ejected at such temperatures. Any slight danger from fire within this 50-foot zone will be entirely eliminated if the sparks permitted to escape from the locomotive are rendered less than ¼ inch in size In other words, every increment in spark size eliminated below the ¼ inch maximum will make locomotive fire prevention assurance doubly sure.

While neither mild nor strong winds materially affect spark, distribution yet the test results, particularly those of Chapter VI. Ignition Powers of Sparks, indicate that winds may help to keep sparks alive and at the same time assist in starting a fire by fanning a glowing spark (one 1200° or over) which has fallen into particularly combustible material. This action, however, only becomes serious when sparks are of sufficient size and contain enough unconsumed carbon to remain alive for a considerable time, three or more seconds. The small spark, even should it contain sufficient unconsumed carbon and glow perceptibly on leaving the stack would, under these conditions, burn itself out much more rapidly than the large spark. That this occurs in less than the time it takes sparks ordinarily to reach the ground is shown by the extensive tests described.

In the last analysis, the general conclusion must be reached from all the evidence gathered that, for the purpose of reducing the fire menace of the locomotive spark, the one most important result to aim at is to reduce the size of the spark to the very lowest limits practicable. In Chapter IV, The Locomotive Spark Arrester, the historic development of the front end, especially with reference to spark prevention, quite effectively demonstrated, after trying all kinds of devices, methods and combinations, wire netting proved to be the one agent whose services to this end were absolutely indispensable. Any other device or arrangement in the front end at best could be but auxiliary to the netting.

As already pointed out, the netting which originally came into quite general use in conjunction with the so-called "Master Mechanics" front end, was the 2½ × 2½ square mesh netting. The thickest spark which could escape through this netting was

¼ inch. Apparently long years of trial and error finally resulted in the selection of this particular type of netting as the best compromise proposition between many conflicting limitations.

The scientific aspect of the netting problem naturally was formulated on the basis of the technical evidence and data which were becoming more and more available as a result of the engineering experiments described in the preceding chapters. It took into more careful consideration the facts, which were becoming increasingly apparent, that locomotive spark fire prevention was primarily synonymous with spark size reduction, and secondarily synonymous with maintaining the locomotive spark arrester in first class condition. Consequently anything by way of design, construction, inspection and handling, that would contribute to maintaining the netting and its supplementary devices in good condition would best serve the purpose of spark fire prevention.

The Draftac netting described in Chapter IV, pages (40–44) seems to meet these conditions. If, therefore, this type of netting, as its principal features would indicate, in conjunction with proper front end inspection and maintenance, will help still further to reduce the spark fire hazard of the locomotive, this fact should be borne out by scientific experiments. Such experiments were made both in the locomotive test laboratory of Purdue University during the spring of 1914, and on the Cleveland, Cincinnati, Chicago & St. Louis Railroad as part of the Big Four Tests just described. These experiments, together with their results, will therefore be presented in detail.

## I. THE PURDUE UNIVERSITY NETTING TESTS[1]

These tests were conducted as a thesis investigation in June 1914, under the supervision of Prof. L. E. Endsley formerly of Purdue University. Their purpose was to determine as accurately as possible what effect (1) square mesh, double crimped, 2½ × 2½ netting with .265-inch by .265-inch openings, (2) perforated steel plate with 3⁄16-inch by 1½-inch openings, and (3) Draftac netting with 3⁄16-inch by ¾-inch openings, would have on (a) large size spark prevention, and (b) resistance to passage of exhaust gases through the front end.

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[1] The information here given concerning these tests was obtained from report made by Prof. L. E. Endsley.

**2. Locomotive Used.**—The locomotive used was the Purdue test locomotive known as Schenectady No. 3. This locomotive was equipped with a self-cleaning "Master Mechanic" type front end. Its arrangement is shown in Figure 99. It will be seen that the table plate extends 10 inches ahead of the center of the nozzle and has a 7-inch lip at the front. Great care was taken to see that all joints between the different plates, netting, and smoke arch were tight so that no sparks could escape unless they passed through the netting proper.

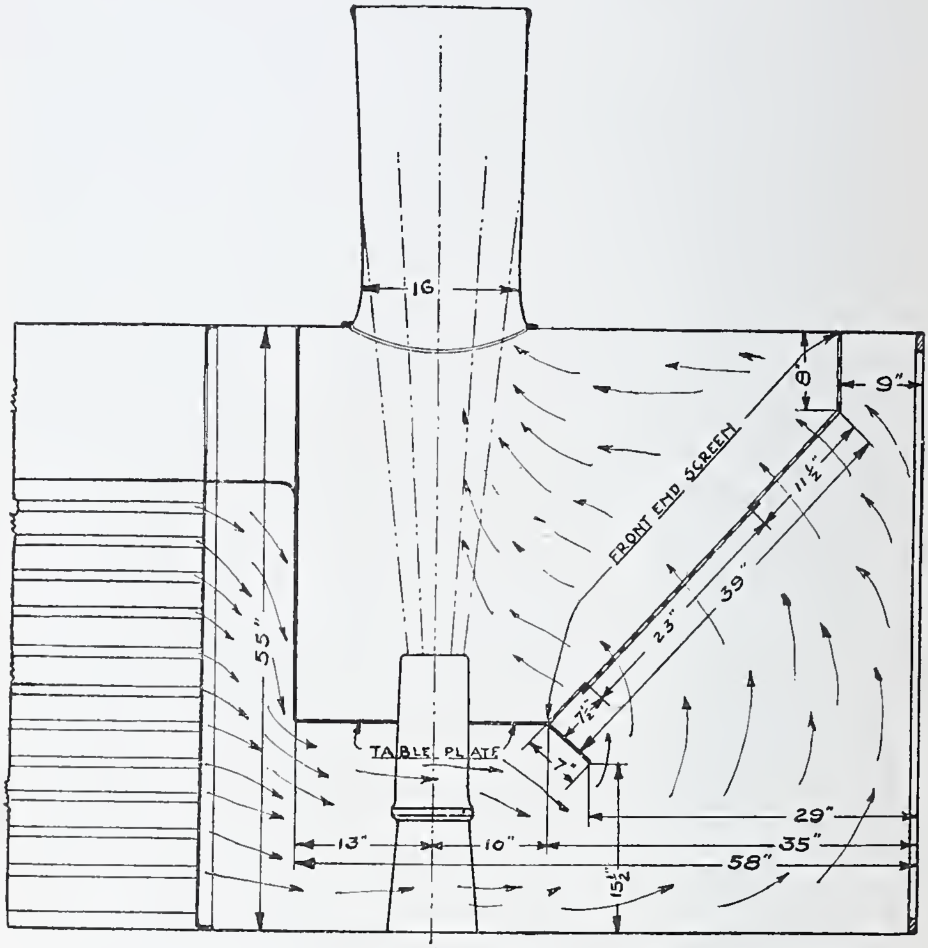


Fig. 99.—Front end arrangement of Purdue University locomotive. Schenectady No. 3.

**3. Description of Spark Catcher.**—For the purpose of collecting all the sparks which left the locomotive, a spark catcher was constructed above the stack. A drawing of this apparatus is shown in Figure 100 and a photograph in Figure 101. The roof of the spark catcher was made of galvanized iron, consisting of two half cylinders with the inner edges riveted together and the concave sides facing downward. This construction gave the path of sparks an easy turn and removed any possibility of break-

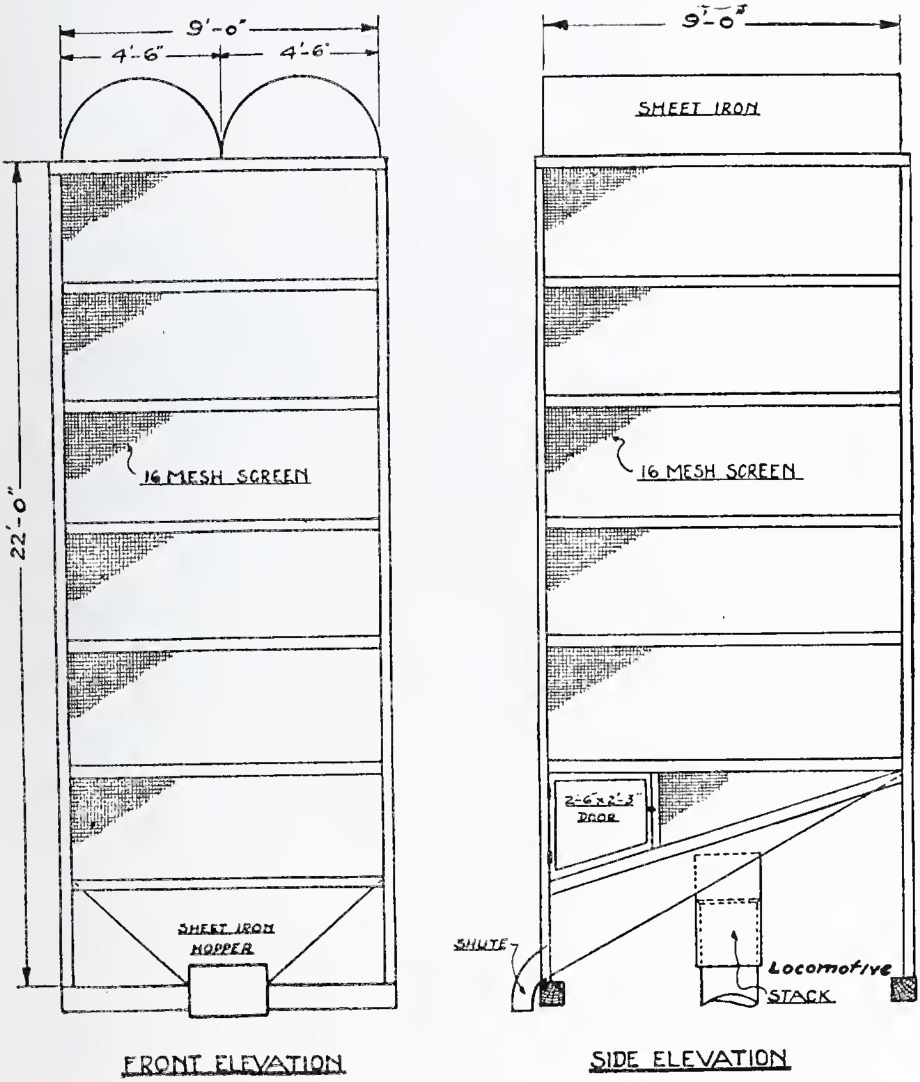


Fig. 100.—Purdue University locomotive laboratory spark catcher.

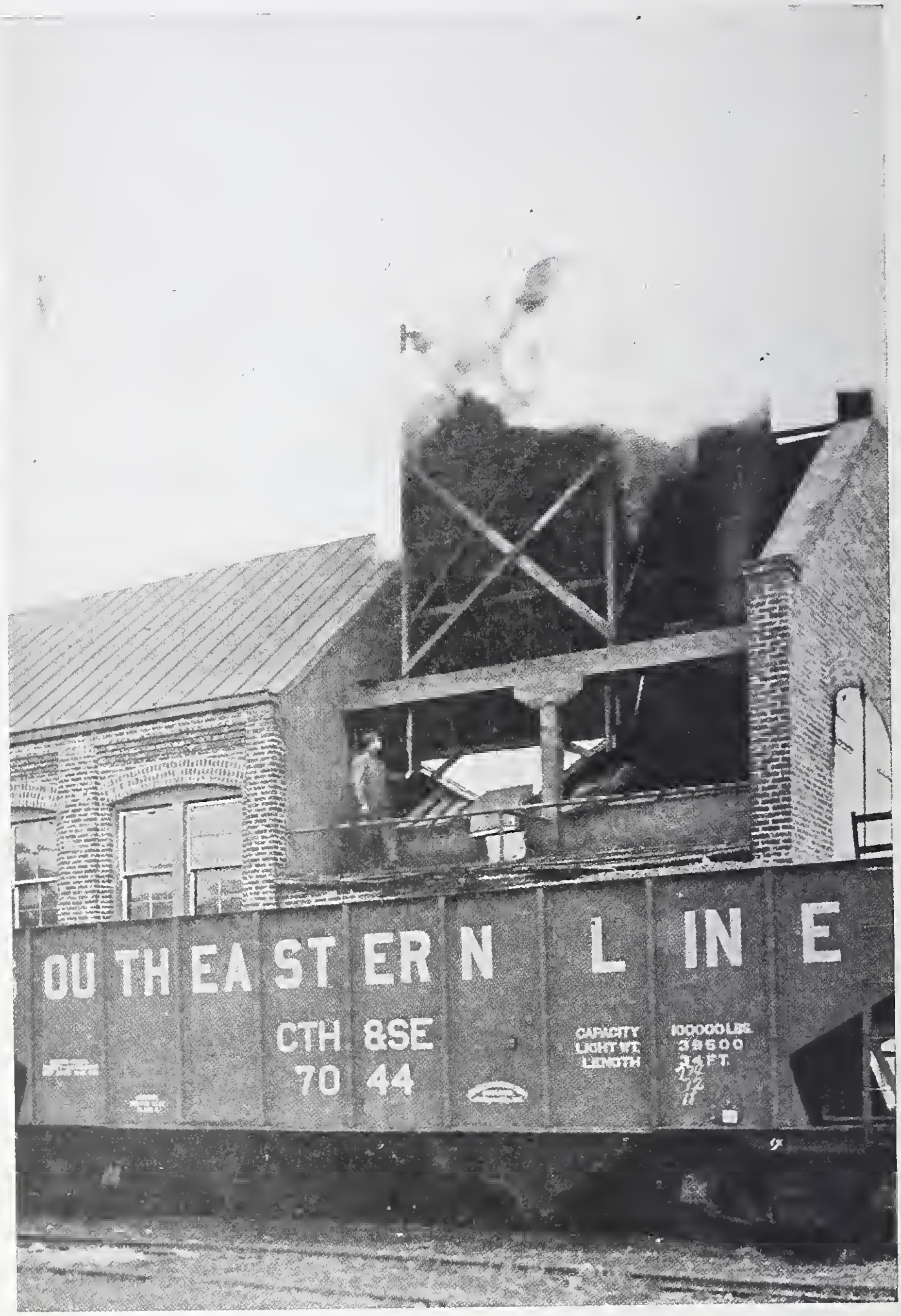


Fig. 101.—Purdue University locomotive laboratory spark catcher in operation.

ing them up. The bottom of the catcher was also made of galvanized iron so constructed that the sparks could be easily removed. The four sides were made of wire cloth 16 mesh to the inch. The arrangement above described was such that all the sparks passing out of the stack which were too large to pass through the 16-mesh cloth were retained in the catcher. Sparks that would pass the 16-mesh wire cloth were not considered of significance in this experiment.

**4. The Locomotive Nettings Tested.**—As stated above, three different kinds of netting were used; namely, square mesh, Draftac, and perforated plate. Photographic reproductions of these nettings, showing actual sizes, as given in Figure 102, and their dimensions are respectively as follows:

### DOUBLE CRIMPED SQUARE MESH NETTING 2½ × 2½ MESH

| | |
|---|---|
| Size of wire (inches) | .135 |
| Opening (inches) | .265 × .265 |
| Number of openings per sq. ft. | 900 |
| Area of opening per square inch | .439 |
| Thus the per cent of opening is | 43.9 |

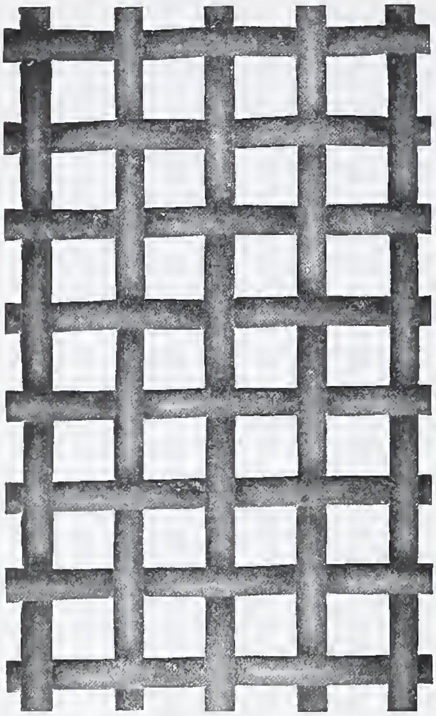
### DRAFTAC NETTING

| | |
|---|---|
| Size of wire (inches) | .135 |
| Width of opening (inches) | .188 |
| Length of opening (inches) | .750 |
| Number of openings per square foot | 561 |
| Area of opening per square inch | .490 |
| Thus the per cent of opening is | 49.0 |

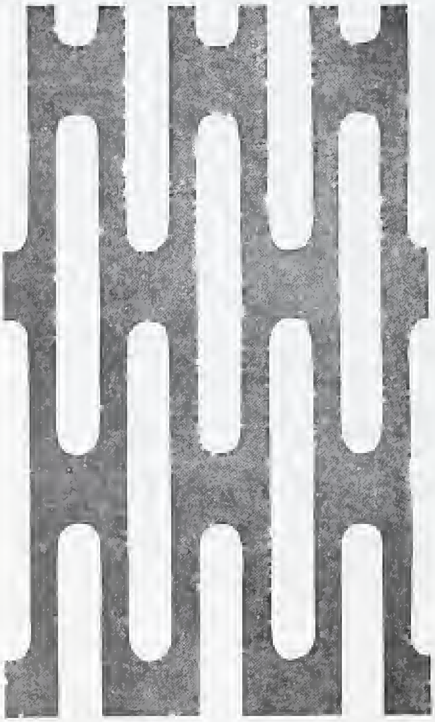
### PERFORATED STEEL PLATE NETTING

| | |
|---|---|
| Width of opening (inches) | .188 |
| Length of opening (inches) | 1.50 |
| Number of openings per square foot | 252 |
| Area of opening per square inch | .477 |
| Thus the per cent of opening is | 47.7 |

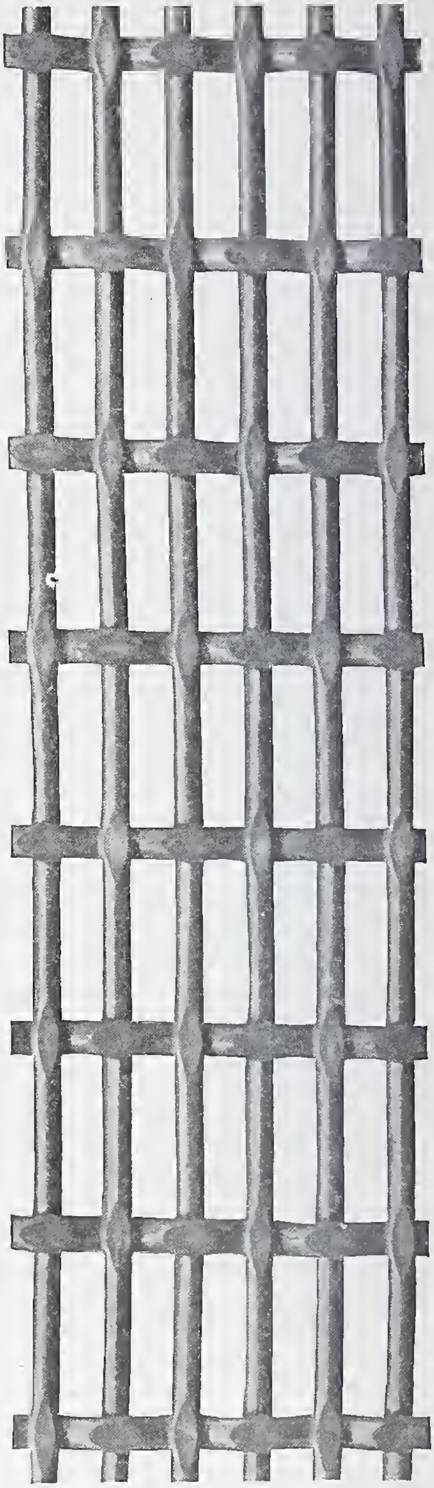
**5. Description of Tests.**—Six tests in all were run, two for each of the three nettings under investigation. The first one of each pair of tests was run at a locomotive speed of 25 miles per hour,



Square mesh 3½″ × 2½ opening.



Perforated plate 3/16″ × 1½″ opening.



Draftac 3/16″ × ¾″ opening.

Fig. 102.—Photographic reproductions of nettings tested in the Purdue Tests.

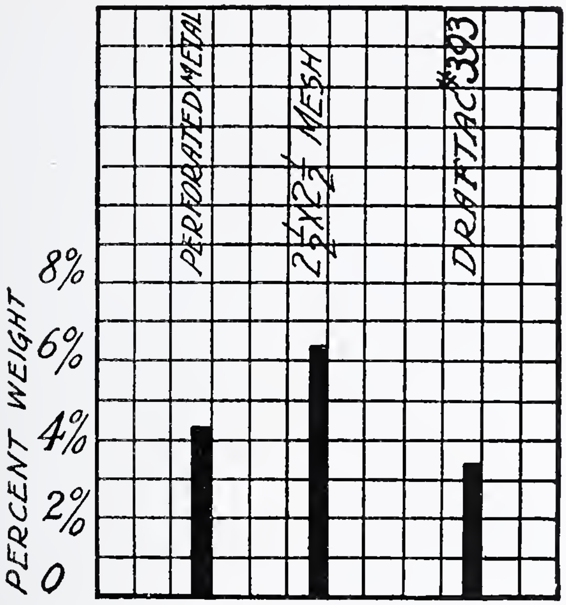


FIG. 103.—Per cent of sparks and cinders that passed through each netting used in the Purdue tests but would not pass through a sieve with $\frac{3}{16}$ inch square openings.

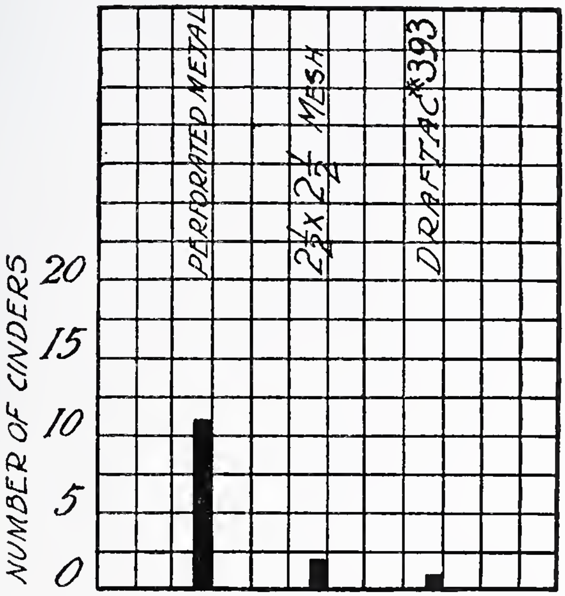


FIG. 104.—Number of sparks and cinders passing front end screens but not passing sieve with $\frac{3}{8}$ inch square openings. Purdue University Netting Tests.

TABLE XX.

| TEST N° | DURATION OF TEST MINUTES | TOTAL REVOLUTIONS OF DRIVERS | MILES PER HOUR CALCULATED | POUNDS PULL BY DYNOMETER | HORSE POWER CALCULATED | TRAIN WEIGHT | FUEL | | | DRAFT | | | | | | | PRESSURE % | | TEMPERATURE | | | WATER | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | KIND OF FUEL | POUNDS CONSUMED | POUNDS PER HORSE POWER HOUR | ASH PAN | FIRE BOX | BACK OF DIAPHRAGM | FRONT OF DIAPHRAGM | FRONT OF NETTING | DIFFERENCE IN FRONT & BACK OF NETTING | PERCENT LOSS DUE TO NETTING | BOILER PRESSURE | BACK PRESSURE IN EXHAUST NOZZLE | SMOKE BOX °F | RIGHT BRANCH PIPE °F | LEFT BRANCH PIPE °F | TOTAL POUNDS EVAPORATED | POUNDS EVAPORATED PER POUND OF COAL |
| I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV | XV | XVI | XVII | XVIII | XIX | XX | XXI | XXII | XXIII | XXIV |
| 1 | 60 | 7258 | 24.8 | 7203 | 478 | 1200 | YOUGHIOGHENY | 1620 | 3.39 | .329 | 1.70 | 3.68 | 5.70 | 5.60 | .100 | 1.78 | 161.1 | 4.82 | 672 | 602 | 586 | 10428 | 6.31 |
| 2 | 60 | 13147 | 45.0 | 4414 | 528 | 630 | ” | 1801 | 3.41 | .291 | 2.03 | 4.04 | 6.33 | 6.23 | .100 | 1.61 | 160.0 | 5.51 | 680 | 607 | 599 | 11397 | 6.31 |
| 3 | 60 | 7249 | 24.2 | 7060 | 465 | 1175 | ” | 1533 | 3.30 | .210 | 1.71 | 3.69 | 5.67 | 5.57 | 100 | 1.80 | 163.0 | 4.77 | 659 | 599 | 593 | 10833 | 7.08 |
| 4 | 60 | 13272 | 45.4 | 4240 | 512 | 607 | ” | 1847 | 3.61 | .379 | 2.24 | 4.20 | 6.40 | 6.29 | .110 | 1.75 | 160.0 | 5.64 | | 608 | 605 | 11272 | 6.10 |
| 5 | 60 | 7345 | 25.2 | 7250 | 472 | 1175 | ” | 1683 | 3.58 | .290 | 2.02 | 3.89 | 5.78 | 5.69 | .09 | 1.58 | 161.0 | 4.87 | 660 | 598 | 590 | 10649 | 6.33 |
| 6 | 60 | 13335 | 45.6 | 4270 | 519 | 610 | ” | 1765 | 3.40 | .350 | 2.50 | 4.49 | 6.61 | 6.54 | .065 | .95 | 161.0 | 5.71 | 672 | 602 | 597 | 11706 | 6.64 |

TABLE XXI.

| TEST N° | NETTING | | | STACK SPARKS | | | | | | | | TABLE PLATE CINDERS | | | | | | | | TOTAL SPARKS PASSING NETTING DURING 2 HOURS RUN | PER CENT OF SPARKS ON $\frac{3}{16}$" NETTING | FRONT END CINDERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DESCRIPTION | OPENINGS PER SQ. FT. | PERCENTAGE OF OPEN AREA | TOTAL AMOUNTS RECOVERED POUNDS | SIZING TEST SIEVE OPENINGS & WTS. IN POUNDS | | | | %WEIGHTS | | | TOTAL AMOUNTS RECOVERED POUNDS | SIZING TEST SIEVE OPENINGS & WTS. IN POUNDS | | | | %WEIGHTS | | | | | TOTAL AMOUNTS RECOVERED POUNDS |
| | | | | | ON $\frac{3}{8}$" | ON $\frac{1}{4}$" | ON $\frac{3}{16}$" | PASS $\frac{3}{16}$" | ON $\frac{1}{4}$" | ON $\frac{3}{16}$" | PASS $\frac{3}{16}$" | | ON $\frac{3}{8}$" | ON $\frac{1}{4}$" | ON $\frac{3}{16}$" | PASS $\frac{3}{16}$" | ON $\frac{1}{4}$" | ON $\frac{3}{16}$" | PASS $\frac{3}{16}$" | | | |
| I | XXV | XXVI | XXVII | XXVIII | XXIX | XXX | XXXI | XXXII | XXXIII | XXXIV | XXXV | XXXVI | XXXVII | XXXVIII | XXXIX | XL | XLI | XLII | XLIII | XLIV | XLV | XLVI |
| 1 | Draftac 393 | 521 | 49 | 79.75 | 0 | .0505 | .87 | 78.88 | .0630 | 1.09 | 98.5 | 85.12 | 1-CINDER | .50 | 6.37 | 78.25 | .58 | 7.50 | 91.8 | 293.87 | 3.42 | 67.68 |
| 2 | ” | 521 | 49 | 129.00 | 0 | .1010 | 2.14 | 126.86 | .079 | 1.66 | 98.2 | | | | | | | | | | | 88.81 |
| 3 | $2\frac{1}{2}$x$2\frac{1}{2}$ MESH | 900 | 43 | 76.06 | 0 | .0225 | 1.75 | 74.31 | .0296 | 2.28 | 97.6 | 107.00 | 1-CINDER | .56 | 11.93 | 94.51 | .522 | 11.10 | 88.3 | 282.18 | 6.19 | 70.31 |
| 4 | ” | 900 | 43 | 99.12 | 1-SPARKS | .0750 | 3.12 | 96.00 | .0756 | 3.15 | 96.8 | | | | | | | | | | | 87.00 |
| 5 | Perforated metal | 252 | 47 | 90.56 | 0 | .065 | 1.37 | 89.18 | .072 | 1.51 | 98.3 | 84.81 | 6-CINDERS | .50 | 8.18 | 76.13 | .59 | 9.65 | 89.3 | 302.74 | 4.35 | 70.18 |
| 6 | ” | 252 | 47 | 127.57 | 5-SPARKS | .134 | 2.93 | 124.43 | .105 | 2.30 | 97.7 | | | | | | | | | | | 107.50 |

and the second at a speed of 45 miles per hour. The duration of all tests was exactly 60 minutes. The steam pressure was maintained constant at 160 pounds. A complete record was kept of the operating conditions of the locomotive.

At the close of each test all the sparks trapped in the spark catcher were carefully removed, weighed, and screened into their size elements. The spark material or "cinders" which remained in the front end, i.e., on the table plate was also carefully removed, weighed and screened.

**6. Data Observed and Tabulated.**—Tables XX and XXI give the observed data and results calculated therefrom. A survey of Table XX shows that the performance of the locomotive during all tests made was practically identical. That is, the pounds of coal burnt and the running speed of the locomotive were very uniform, so much so that no compensating allowances had to be made in order to adjust the final results to a common basis.

TABLE XXI

| TEST NUMBER | NETTING TESTED | HOURS DURATION | MILES PER HOUR | SPARKS PASSING FRONT END NETTING | | | | | CINDERS NOT PASSING FRONT END NETTING POUNDS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | TOTAL POUNDS | SIZING TEST | | | | |
| | | | | | | PERCENTAGE WTS. | | | |
| | | | | | NOT PASSING $\frac{3}{8}$" □ OPENING | NOT PASSING $\frac{1}{4}$" □ OPENING | NOT PASSING $\frac{3}{16}$" □ OPENING | PASSING $\frac{3}{16}$" □ OPENING | |
| 1 AND 2 | DRAFTAC #393 | 1<br>1 | 25<br>45 | 293.9 | 1 CINDER | 0.2 | 3.2 | 96.6 | 156 |
| 3 AND 4 | $2\frac{1}{2}$X$2\frac{1}{2}$ MESH | 1<br>1 | 25<br>45 | 282.2 | 2 CINDERS | 0.2 | 5.9 | 93.8 | 157 |
| 5 AND 6 | PERFORATED METAL | 1<br>1 | 25<br>45 | 302.7 | 11 CINDERS | 0.2 | 4.1 | 95.7 | 177 |

**7. Summary of Results.**—It will be seen from Table XXII—Summary of All Tests, final column, that the weight of sparks held in the front end was 156 pounds for the Draftac netting, 157 pounds for the square mesh netting and 177 pounds for the perforated plate netting, the amount being greatest in the case of the latter.

The relative efficiencies of the three nettings are shown in Figure 103. These have been plotted from Column XLV of Table XXI. This column shows the percentage of sparks which passed the front end nettings but did not pass the screen with 3/16-inch square openings during the sifting operations. The values indicated in Figure 103 show that the amount of these sparks was 38% greater in the case of the perforated plate netting and 77% greater in the case of the square mesh netting, than in the case of Draftac netting.

Of the sparks passing Draftac netting, only 3.5% failed to pass the 3/16-inch screen, while over 6% of the sparks which passed the square mesh netting failed to pass the 3/16-inch screen. The results for the perforated metal plate fall about half-way between these results.

After the test of each netting a few sparks and cinders respectively were found which would not pass through the 3/8-inch square opening sifting screen. The cinders, as is shown in Table XXI, were removed from the table plate of the front end. Thus they had actually passed through the netting but had not yet been ejected from the stack. The 3/8-inch sparks were taken from the spark catcher and found as a result of screening the contents of this catcher after each series of the two tests with each screen.

The number of these large sparks and table plate cinders, was counted in each case. The results are indicated in Columns XXIX and XXXVII of Table XXI. They have also been plotted in Figure 104. It will be seen from the table and figure that eleven in all of these large sparks and cinders passed through the perforated metal plate netting, two through the square mesh netting and only one through Draftac netting.

## II. BIG FOUR TESTS WITH DRAFTAC NETTING

These tests were part of the general series already described in Chapter VIII, conducted under the following conditions:

Series No. IV.—Four tests using Draftac netting—3⁄16-inch by ¾-inch opening in good condition; nozzle opening 5¾ inch; throttle wide open; and locomotive hand fired.

Series No. V.—Four tests using Draftac netting in good condition; nozzle opening 5¾ inch; throttle wide open; locomotive stoker fired.

The test procedure, apparatus and locomotive, i.e., Big Four Mikado No. 6089, were all the same, except that the front end of the test locomotive was equipped with Draftac netting. This installation is shown in Figure 105. The tabulation of test results and observations made also followed the previous tests.

**8. Data Observed and Tabulated.**—Figure 106 shows the spark losses which result when using Draftac netting under the same conditions as in the tests of Series No. II, whose results were shown in Figure 91 (page 172, Chapter VIII), i.e., Locomotive No. 6089 was hand fired, and equipped with square mesh netting. During the tests of this series (No. IV) mild winds of from 6 to 8 miles per hour were blowing.

Figure 107, based on the data of Series No. V, shows the spark losses which result when using Draftac netting under the same conditions as in the tests of Series No. 1 whose results were shown in Figure 90 (page 172, Chapter VIII), i.e., when Locomotive No. 6089 was stoker fired, and equipped with square mesh netting.

Figure 108 is a combination of the results shown in Figure 91 and Figure 106. Thus it compares the effect of Draftac netting with square mesh netting on spark prevention in the case of a modern Mikado freight locomotive when hand fired.

Figure 109 on the other hand is a combination of the results shown in Figure 90 and Figure 106 and thus compares the effect of Draftac netting with square mesh netting on spark prevention in the case of a modern Mikado freight locomotive when stoker fired.

Figure 110 is a combination of Figures 106 and 107, and thus compares the spark distribution characteristics of the Mikado freight locomotive under observation equipped with Draftac netting (1) when hand fired with (2) when stoker fired.

Finally Figure 111 presents a comparison of the various spark prevention and distribution results of Big Four Test Series Nos. I, II, VII, and IX, that is when the locomotives under observation were equipped with ordinary square mesh netting, with the results of series Nos. IV and V when the locomotive under observation was equipped with Draftac netting. Table XXIII compares the number of hot sparks caught during the

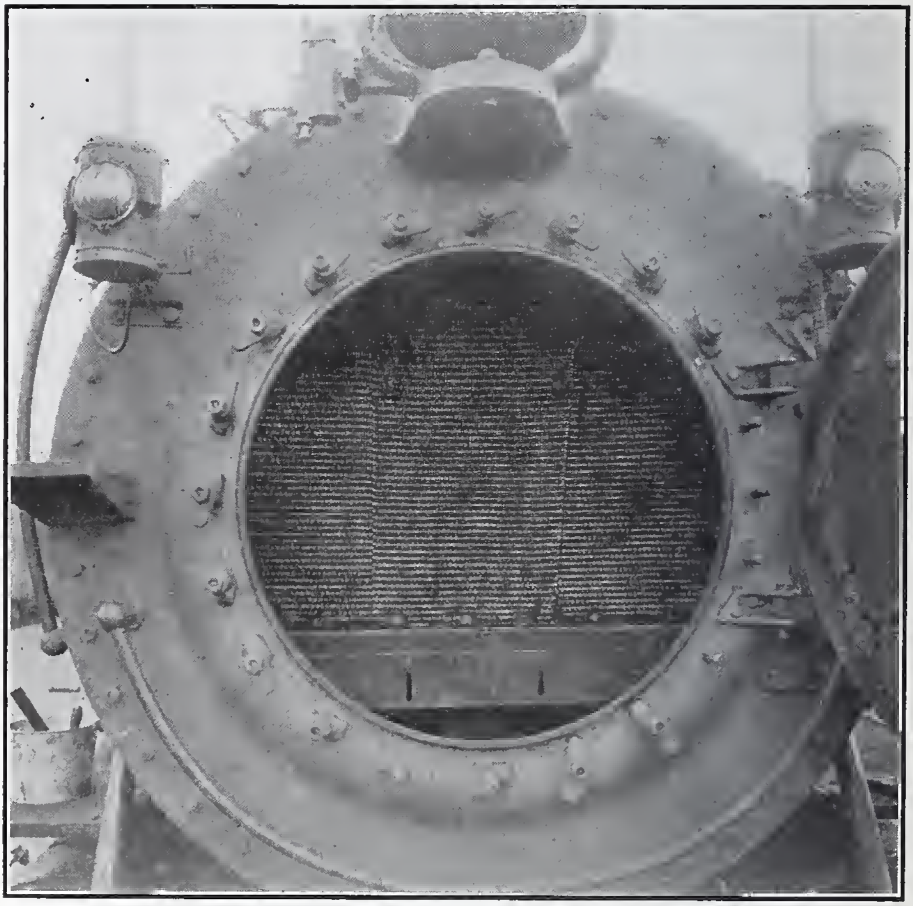
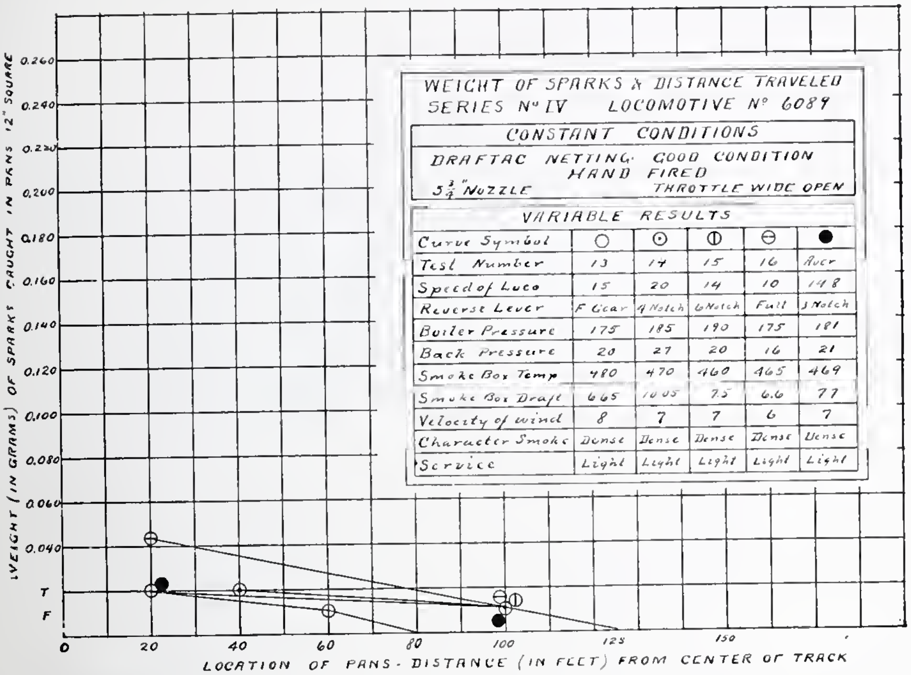


Fig. 105.—Front end view of Big Four Test locomotive No. 6089 showing Draftac netting installation.



WEIGHT OF SPARKS & DISTANCE TRAVELED
SERIES Nº IV LOCOMOTIVE Nº 6089

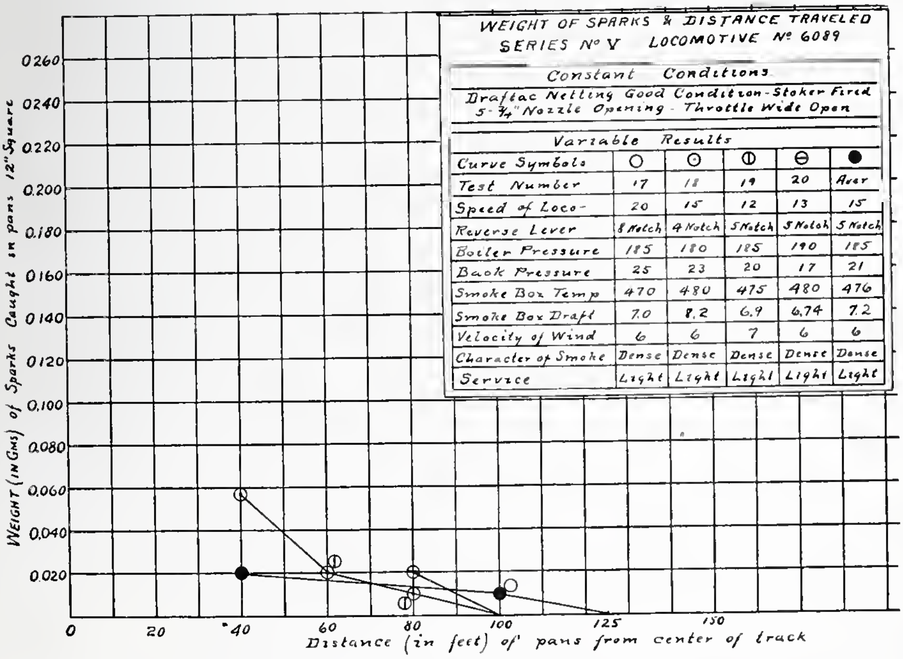
CONSTANT CONDITIONS

DRAFTAC NETTING GOOD CONDITION
HAND FIRED
$5\frac{3}{4}$" NOZZLE THROTTLE WIDE OPEN

VARIABLE RESULTS

| Curve Symbol | ○ | ⊙ | ⦶ | ⊖ | ● |
|---|---|---|---|---|---|
| Test Number | 13 | 14 | 15 | 16 | Aver |
| Speed of Loco | 15 | 20 | 14 | 10 | 14.8 |
| Reverse Lever | F Gear | 4 Notch | 6 Notch | Full | 5 Notch |
| Boiler Pressure | 175 | 185 | 190 | 175 | 181 |
| Back Pressure | 20 | 27 | 20 | 16 | 21 |
| Smoke Box Temp | 480 | 470 | 460 | 465 | 469 |
| Smoke Box Draft | 6.65 | 10.05 | 7.5 | 6.6 | 7.7 |
| Velocity of wind | 8 | 7 | 7 | 6 | 7 |
| Character Smoke | Dense | Dense | Dense | Dense | Dense |
| Service | Light | Light | Light | Light | Light |

FIG. 106.—Relation between weight of sparks caught and distance from center of track. Locomotive hand fired and equipped with Draftac netting, Big Four Test Series IV.



WEIGHT OF SPARKS & DISTANCE TRAVELED
SERIES Nº V LOCOMOTIVE Nº 6089

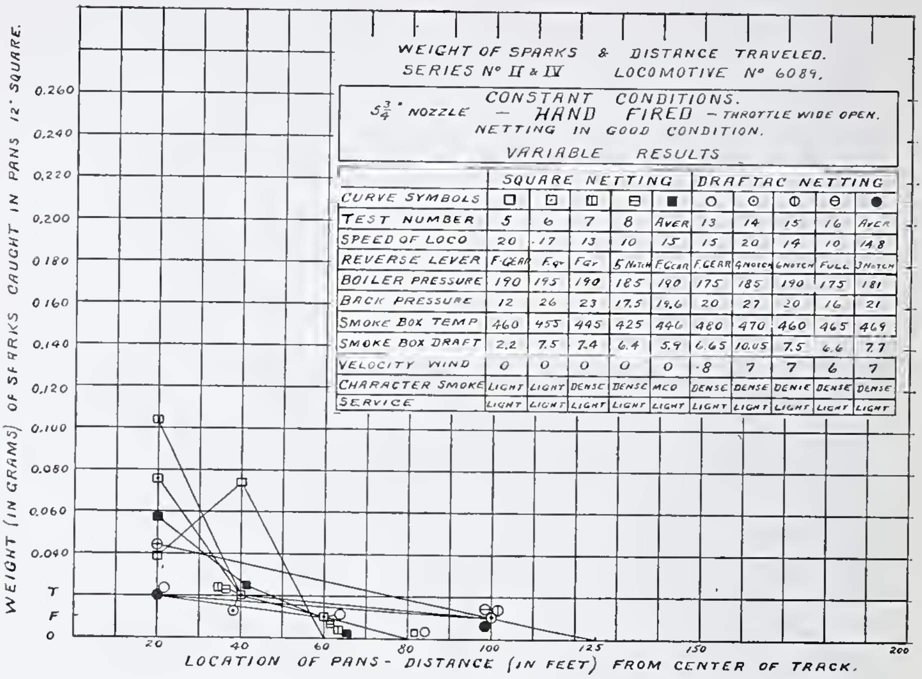
Constant Conditions

Draftac Netting Good Condition - Stoker Fired
5-¾" Nozzle Opening - Throttle Wide Open

Variable Results

| Curve Symbols | ○ | ⊙ | ⦶ | ⊖ | ● |
|---|---|---|---|---|---|
| Test Number | 17 | 18 | 19 | 20 | Aver |
| Speed of Loco- | 20 | 15 | 12 | 13 | 15 |
| Reverse Lever | 8 Notch | 4 Notch | 5 Notch | 5 Notch | 5 Notch |
| Boiler Pressure | 185 | 180 | 185 | 190 | 185 |
| Back Pressure | 25 | 23 | 20 | 17 | 21 |
| Smoke Box Temp | 470 | 480 | 475 | 480 | 476 |
| Smoke Box Draft | 7.0 | 8.2 | 6.9 | 6.74 | 7.2 |
| Velocity of Wind | 6 | 6 | 7 | 6 | 6 |
| Character of Smoke | Dense | Dense | Dense | Dense | Dense |
| Service | Light | Light | Light | Light | Light |

FIG. 107.—Relation between weight of sparks caught and distance from center of track. Locomotive stoker fired and equipped with Draftac netting. Big Four Test Series No. V.

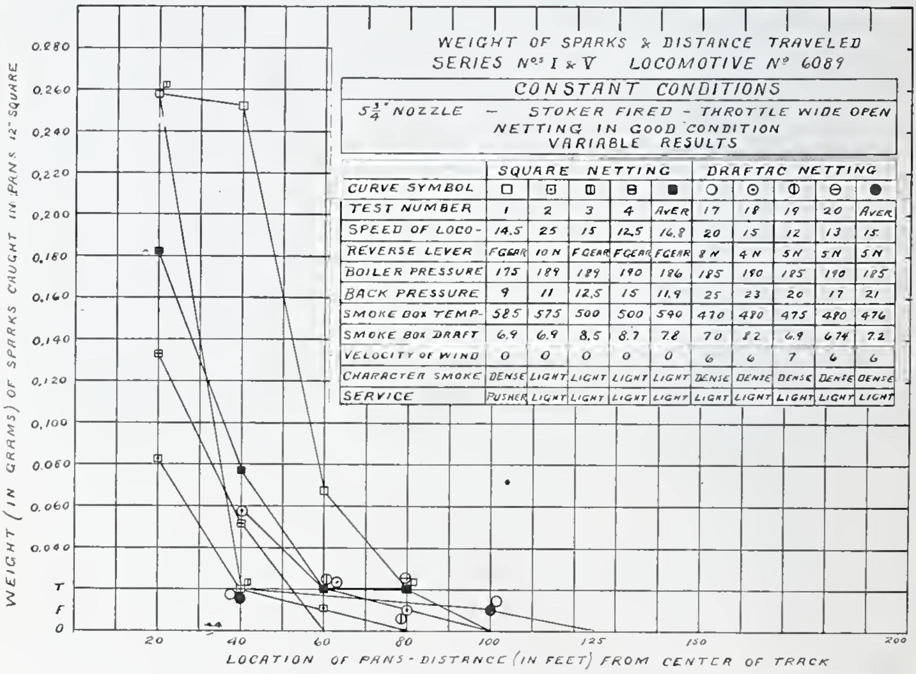


WEIGHT OF SPARKS & DISTANCE TRAVELED.
SERIES N° II & IV LOCOMOTIVE N° 6089.

CONSTANT CONDITIONS.
$5\frac{3}{4}$" NOZZLE — HAND FIRED — THROTTLE WIDE OPEN.
NETTING IN GOOD CONDITION.
VARIABLE RESULTS

| | SQUARE NETTING | | | | | DRAFTAC NETTING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CURVE SYMBOLS | □ | ⊡ | ◫ | ⊟ | ■ | ○ | ⊙ | ⦶ | ⊖ | ● |
| TEST NUMBER | 5 | 6 | 7 | 8 | AVER | 13 | 14 | 15 | 16 | AVER |
| SPEED OF LOCO | 20 | 17 | 13 | 10 | 15 | 15 | 20 | 14 | 10 | 14.8 |
| REVERSE LEVER | F. GEAR | F. Gr | F. Gr | 5 NOTCH | F. GEAR | F. GEAR | 4 NOTCH | 6 NOTCH | FULL | 3 NOTCH |
| BOILER PRESSURE | 190 | 195 | 190 | 185 | 190 | 175 | 185 | 190 | 175 | 181 |
| BACK PRESSURE | 12 | 26 | 23 | 17.5 | 19.6 | 20 | 27 | 20 | 16 | 21 |
| SMOKE BOX TEMP | 460 | 455 | 445 | 425 | 446 | 480 | 470 | 460 | 465 | 469 |
| SMOKE BOX DRAFT | 2.2 | 7.5 | 7.4 | 6.4 | 5.9 | 6.65 | 10.05 | 7.5 | 6.6 | 7.7 |
| VELOCITY WIND | 0 | 0 | 0 | 0 | 0 | 8 | 7 | 7 | 6 | 7 |
| CHARACTER SMOKE | LIGHT | LIGHT | DENSE | DENSE | MED | DENSE | DENSE | DENSE | DENSE | DENSE |
| SERVICE | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT |

FIG. 108.—Comparison of spark distribution results, square mesh netting and Draftac netting, locomotive hand fired. Big Four Test Series No. II and IV.

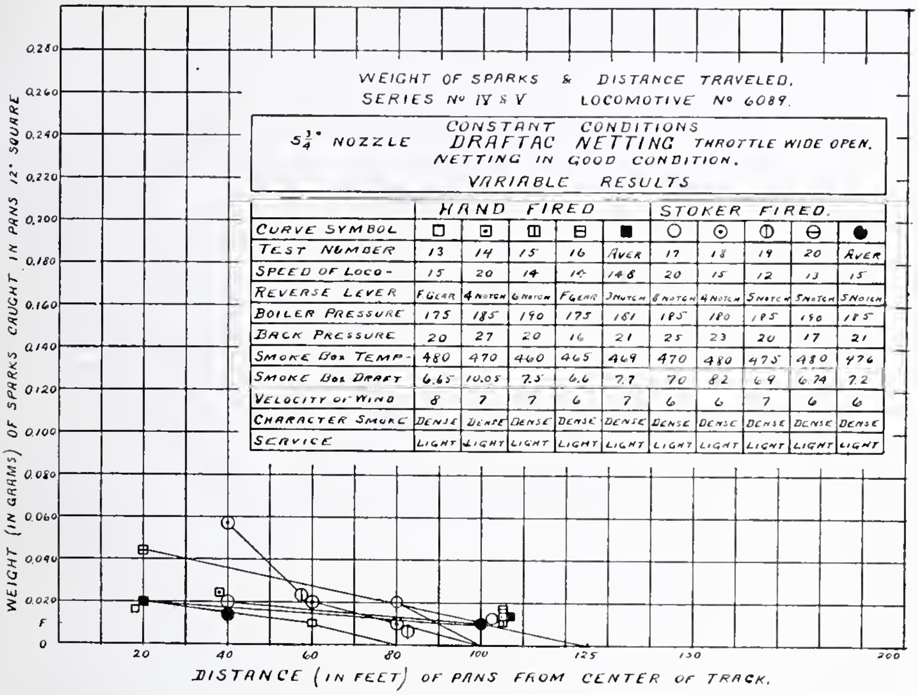


WEIGHT OF SPARKS & DISTANCE TRAVELED
SERIES N°s I & V LOCOMOTIVE N° 6089

CONSTANT CONDITIONS
$5\frac{3}{4}$" NOZZLE — STOKER FIRED — THROTTLE WIDE OPEN
NETTING IN GOOD CONDITION
VARIABLE RESULTS

| | SQUARE NETTING | | | | | DRAFTAC NETTING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CURVE SYMBOL | □ | ⊡ | ◫ | ⊟ | ■ | ○ | ⊙ | ⦶ | ⊖ | ● |
| TEST NUMBER | 1 | 2 | 3 | 4 | AVER | 17 | 18 | 19 | 20 | AVER |
| SPEED OF LOCO- | 14.5 | 25 | 15 | 12.5 | 16.8 | 20 | 15 | 12 | 13 | 15 |
| REVERSE LEVER | F GEAR | 10 N | F GEAR | F GEAR | F GEAR | 8 N | 4 N | 5 N | 5 N | 5 N |
| BOILER PRESSURE | 175 | 189 | 189 | 190 | 186 | 185 | 190 | 185 | 190 | 185 |
| BACK PRESSURE | 9 | 11 | 12.5 | 15 | 11.9 | 25 | 23 | 20 | 17 | 21 |
| SMOKE BOX TEMP- | 585 | 575 | 500 | 500 | 540 | 470 | 480 | 475 | 480 | 476 |
| SMOKE BOX DRAFT | 6.9 | 6.9 | 8.5 | 8.7 | 7.8 | 7.0 | 8.2 | 6.9 | 6.74 | 7.2 |
| VELOCITY OF WIND | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 7 | 6 | 6 |
| CHARACTER SMOKE | DENSE | LIGHT | LIGHT | LIGHT | LIGHT | DENSE | DENSE | DENSE | DENSE | DENSE |
| SERVICE | PUSHER | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT |

FIG. 109.—Comparison of spark distribution results, square mesh netting and Draftac netting locomotive stoker fired. Big Four Test Series I and V.



| | HAND FIRED | | | | | STOKER FIRED. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CURVE SYMBOL | □ | ⊡ | ◫ | ⊟ | ■ | ○ | ⊙ | ⦶ | ⊖ | ● |
| TEST NUMBER | 13 | 14 | 15 | 16 | AVER | 17 | 18 | 19 | 20 | AVER |
| SPEED OF LOCO- | 15 | 20 | 14 | 14 | 14.8 | 20 | 15 | 12 | 13 | 15 |
| REVERSE LEVER | F. GEAR | 4 NOTCH | 6 NOTCH | F. GEAR | 3 NOTCH | 8 NOTCH | 4 NOTCH | 5 NOTCH | 5 NOTCH | 5 NOTCH |
| BOILER PRESSURE | 175 | 185 | 190 | 175 | 181 | 185 | 180 | 185 | 190 | 185 |
| BACK PRESSURE | 20 | 27 | 20 | 16 | 21 | 25 | 23 | 20 | 17 | 21 |
| SMOKE BOX TEMP- | 480 | 470 | 460 | 465 | 469 | 470 | 480 | 475 | 480 | 476 |
| SMOKE BOX DRAFT | 6.65 | 10.05 | 7.5 | 6.6 | 7.7 | 70 | 82 | 69 | 6.74 | 7.2 |
| VELOCITY OF WIND | 8 | 7 | 7 | 6 | 7 | 6 | 6 | 7 | 6 | 6 |
| CHARACTER SMOKE | DENSE | DENSE | DENSE | DENSE | DENSE | DENSE | DENSE | DENSE | DENSE | DENSE |
| SERVICE | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT | LIGHT |

FIG. 110.—Comparison of spark distribution results, Draftac netting, locomotive stoker fired vs. hand fired. Big Four Test Series IV and V.

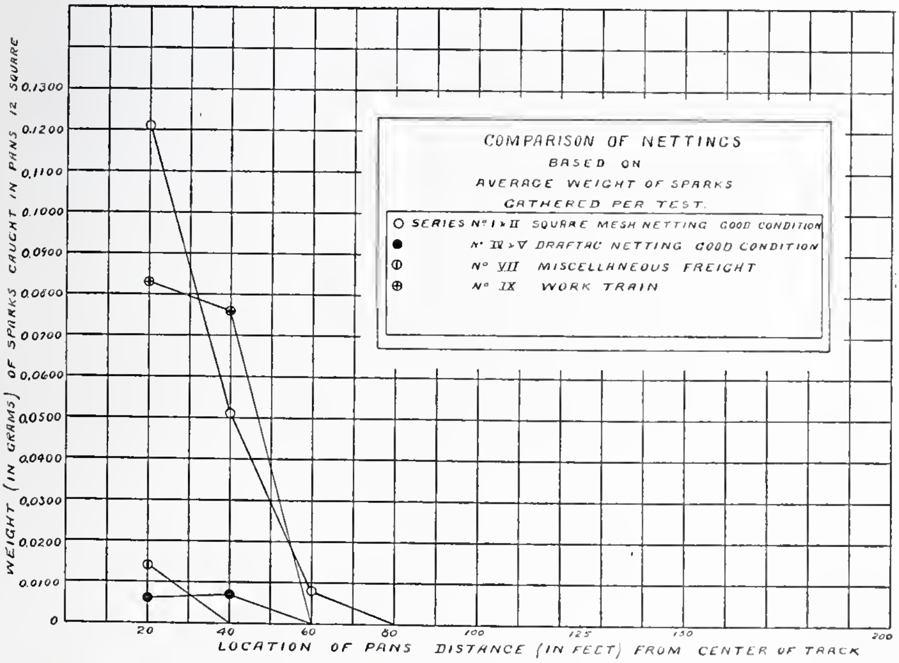


FIG. 111.—Comparison of average spark distribution results, square mesh netting, and Draftac netting. All tests of Big Four Series.

tests when the locomotives were equipped with Draftac netting with those caught during the other tests.

TABLE XXIII.—COMPARISON OF NUMBER OF WARM SPARKS CAUGHT DURING DRAFTAC TESTS WITH THOSE CAUGHT DURING OTHER BIG FOUR TESTS

| Rows of pans | Series of constant test conditions | | | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | IV | V | VII | VIII | IX |
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 1 | 0 | 0 | 2 | 5 | 1 | 10 |
| C | 0 | 0 | 0 | 0 | 11 | 0 | 1 |
| D | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Total | 1 | 0 | 0 | 2 | 17 | 1 | 13 |
| Number of tests | 4 | 4 | 4 | 4 | 6 | 6 | 4 |
| Average per series | 0.25 | 0 | 0 | 0.50 | 2.83 | 0.17 | 3.25 |

**9. Summary of Results.**—A study of the various figures presented reveals that Draftac netting in the hand-fired locomotive tests (Series IV) so effectively prevented the ejection of sparks approaching the ¼-inch size that no spark with perceptible weight passed beyond the 20-foot limit; whereas such sparks were found beyond the 40-foot limit, when the same locomotive employed square mesh netting. It is true that traces of sparks during Series IV were found beyond the 100-foot limit, but this would seem rather to indicate that this type of netting was instrumental in breaking down a larger quantity of sparks into fine particles which would be more or less apt to float away, especially with winds blowing, as was true in these tests.

The effect of Draftac netting on the spark distribution characteristics of the test locomotive stoker-fired compared with the effect of square mesh netting, in this locomotive as revealed by Figure 111, indicates that this particular netting is an effective agent in helping the front end accomplish one of its two purposes, i.e., making locomotive sparks harmless. All the figures, as well as Table XXIII, confirm the above indications, that Draftac netting, while actually increasing the draft area through the netting, at the same time very effectively reduces the size of the sparks.

**10. Conclusions as to Front End Netting and Its Relation to Locomotive Spark Fire Prevention.**—On the basis of the test results just summarized, the following specific conclusions are warranted with respect to the effect of Draftac netting on the formation of dangerous fire carrying sparks in the operation of steam locomotives.

1. This type of netting effectively reduces locomotive sparks below the ¼-inch size before permitting them to escape from the stack.
2. In doing this, the netting does not increase the resistance of the gaseous products of combustion through the locomotive front end.
3. It follows from the foregoing that in accordance with these experiments that Draftac netting, when employed in the locomotive front end, will, in conjunction with proper inspection and maintenance afford the best practical protection from fires from locomotive sparks.

## III. GENERAL CONCLUSIONS WITH RESPECT TO LOCOMOTIVE SPARK FIRE PREVENTION

In Chapter VII and VIII as well as in this chapter a series of specific conclusions have been stated concerning respectively the ignition properties of locomotive sparks, the distribution of locomotive sparks, and the effect of improved netting on locomotive spark formation. As already indicated, each one of these conclusions has a definite relation to the general problem of locomotive fire prevention which has been outlined in the early part of this chapter. The last of these conclusions having now been stated, i.e. in the preceding paragraph, it finally becomes possible to summarize and present the conclusions in general which follow concerning the broader aspects of locomotive spark fire prevention. These may be stated as follows:

1. The most effective single agent available for locomotive spark prevention is front end netting.

2. Any improvements to the netting therefore which does not reduce the free area through it, but which prevents the escape of sparks greater than $\frac{3}{16}$ inch in thickness, will, when properly employed in locomotive front ends, confine the spark fire hazard of such locomotives well within safe limits.

3. If, in addition to improved netting of this kind, improvements in front end design and construction are utilized, making possible better and more thorough inspection together with greater ease of maintenance—such as is intended to result from the application of some of the devices described in Chapter IV. The Locomotive Spark Arrester—locomotives so equipped will be about as free from spark fire dangers as it is possible to make them.

4. Conclusion No. 3, however is only true as long as locomotive front ends and their detail parts are regularly and thoroughly inspected, and adequately, properly and effectively maintained. In other words the very best of front end netting and the most improved spark arresting devices will be to no avail in preventing dangerous sparks from leaving the locomotive stacks if these devices are not conscientiously looked over and kept in first class repair at all times. Above all else, therefore, the essence of locomotive spark fire prevention is thorough regular front end inspection and maintenance.

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